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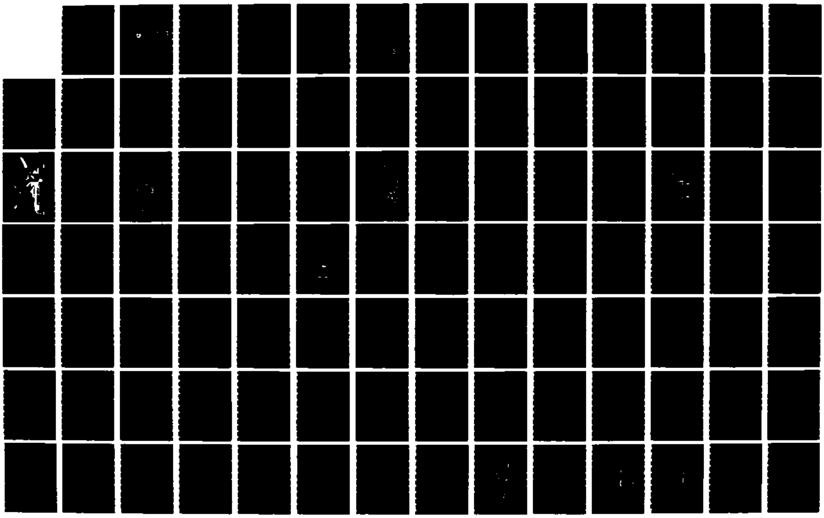

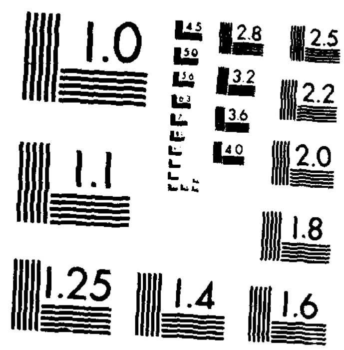
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Report No. CG-D-24-86

EARLY DEVELOPMENT OF A HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

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U. S. Coast Guard
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FINAL REPORT

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16. Abstract

is described

This report describes a U. S. Coast Guard program for developing a Hazardous Chemical Protective Ensemble for protection of personnel during chemical spill response. ~~This work involved the~~ selection and testing of chemically resistant materials, ~~the~~ design of a totally encapsulating suit employing the selected materials, ~~the~~ design of a full body cooling garment, ~~the~~ construction of prototype suits, and laboratory evaluation of the complete ensemble are discussed.

The Coast Guard chose butyl rubber, chlorinated polyethylene, and VITON/chlorobutyl laminate for outergarment materials, and fluorinated ethylene propylene-surlyn laminate as the visor material for a three material suit 'system'. Material selection criteria involved chemical resistance, physical properties, and the material's ability to form high integrity seams. Immersion testing was performed for 160 chemicals and permeation against 56 chemicals for each of the selected materials. Suit seam chemical resistance and material decontamination potential were ~~also~~ investigated.

The outergarment was designed to accomodate the cooling system and a variety of commercial breathing and communication devices. Features of the outergarment included a pressure-sealing zipper, integral gloves, sock-like booties, and internal positive pressure. The cooling system was designed to interface directly with the outergarment with a full body cooling garment, pump, and field-serviced ice pouch/heat exchanger.

Laboratory evaluations included protection factor testing to measure ensemble integrity and manned stress testing to assess ensemble function, fit, and comfort.

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Hazardous Chemical Protective Ensemble Totally-encapsulating suit Chemical protective materials Chemical resistance testing Immersion/Permeation testing	This document is available to the U. S. public through the National Technical Information Service, Springfield, VA 22161.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

The U. S. Coast Guard has the responsibility for the containment and clean-up of chemical spills on the nation's coastal and inland waterways. To aid in the response to these spills the Coast Guard developed the Chemical Hazardous Response Information System (CHRIS)[1], which defines the chemical properties and relative hazards associated with each of the 1100 chemicals listed. The chemicals included in the CHRIS manuals are those chemicals known to be transported within the boundaries of the United States. Over 400 of the 1100 chemicals included in the CHRIS list have been identified as requiring the use of a totally encapsulating protective garments during spill response.

At the time the work in this report began, the U. S. Coast Guard had no one standardized encapsulating protective garment and was utilizing a variety of commercially available products. The majority of the Coast Guard's early totally encapsulating protective ensembles were constructed primarily of butyl rubber with a polycarbonate visor material. One such encapsulating protective garment was the Hazardous Chemical Protective Clothing Outfit (HCPCO). This garment was fabricated from butyl rubber coated nylon with a polycarbonate helmet and incorporated a powered air purifying respirator. The respirator drew contaminated air through a filter to purify it prior to distributing it within the ensemble as breathing and cooling air.

A study performed for the U. S. Coast Guard (Ref. 2) determined that butyl rubber was compatible with 155 of the 403 chemicals that required a totally encapsulating garment, and incompatible with 187 chemicals, while the compatibility of 61 chemicals could not be determined. The polycarbonate helmet material was found to be compatible with 241 chemicals, incompatible with 119 chemicals, and 43 chemicals were not tested. Other factors limiting the use of the HCPCO were the inability to operate the air purifying respirator in an oxygen deficient atmospheres, and the filter medium's incompatibility with several chemical environments.

Beginning in 1979, ILC Dover was funded by the U. S. Army Chemical Systems Laboratory, Aberdeen, MD and the U. S. Coast Guard under contracts DAAK11-80-C-0020 and DAAK11-80-C-0059 to develop, fabricate, test, and deliver chemical protective ensembles, each consisting of a modified Demilitarization Protective Ensemble (DPE), a self-contained breathing system, and a liquid cooling system. During the interim period prior to the development of the proposed hazardous chemical protective ensemble under this contract, the Coast Guard procured and included in its inventory a variety of commercially available encapsulating suits. Several ensembles were based on the designs developed in the above contracts. These included the ILC Dover Model 51 Chemturions which are fabricated from an alloyed chlorinated polyethylene (CPE) material, which was the same material used in the DPE outergarment. The breathing system in the Army contract was designed to provide one hour of breathing air to the user, and had a liquid cooling garment for the upper body.

In 1981, the U. S. Coast Guard issued a solicitation with a Request for

Proposals to develop a new Hazardous Chemical Protective Ensemble. The contract was awarded to ILC Dover with the principal objectives of investigating protective materials which provided a wider range of compatability to the CHRIS chemicals, and designing overgarments which could accomodate a variety of breathing systems and other protective equipment. The use of a uniform design was a primary criterion to avoid ensembles having different training and maintenance requirements. The Coast Guard's original requirements for the Hazardsous Chemical Protective Ensemble are listed in Table 1.

This report summarizes the work performed during the four task program to develop a Hazardous Chemical Protective Ensemble for the Coast Guard. This work involved the design of a totally encapsulated protective ensemble using materials that would provide protection to as many hazardous chemicals as possible, testing of the suits, and development of final specifications. The specific tasks in this program included:

1. Task I - Selection of Chemical Protective Materials and Compatibility Testing.

   The objective of this task was to identify materials that are resistant to the chemicals that were found to be incompatible with butyl or polycarbonate in a previous test program. Verification of the compatibility of the selected materials was accomplished by a compatibility test program that consisted of an immersion test phase to determine the extent of physical attack by the chemicals on the material, and permeation testing to determine the effectiveness of the material as a barrier against the chemicals. Additionally, seam chemical resistance and material decontamination potential were investigated.

2. Task II - Design of the Hazardous Chemical Protective Ensemble.

   The objective of this task was to develop an ensemble that integrates the materials selected in task I, along with Coast Guard selected respiratory protection, a body cooling system, an internal suit pressurization system, and Coast Guard provided communications into a single design. The design characteristics developed in this task identified a totally encapsulating, self-supporting protective ensemble capable of meeting Coast Guard requirements.

3. Task III - Fabrication of Preliminary Prototype Ensembles.

   The objective of this task was to fabricate prototype total encapsulating suits of each selected material. Six suits were constructed including two VITON/chlorobutyl laminate suits, two butyl rubber suits, one 30 mil unsupported chlorinated polyethylene suit, and one 20 mil supported chlorinated polyethylene suit. These total encapsulating suits were built according to preliminary drawings and specifications developed in Task II. The resulting suits were completed and fully operational to interface with government provided breathing appartuses, communications equipment, and the ILC Dover designed full body cooling suit.

TABLE 1

ORIGINAL COAST GUARD ENSEMBLE REQUIREMENTS

ITEM	REQUIREMENT
Time Limit	
Wear Time	3 hours
Chemical Service Time	
Primary level-1st use	3 hours
No. wear cycles	1 (disposable)
Shelf Life	3 years
Ambient Work Conditions	
Pressure	1 Atmosphere (Air with no contaminant to 100% contaminant)
Temperature	-30°C (-22°F) to 40°C (104°F)
Humidity	Up to 100%-water contact is probable
Sunlight	No Ultraviolet (UV) or Ozone (O_3) degradation
Fungus	Will not support mold growth
Storage Conditions	
Stability	Non-cracking, no blocking, stiffening, flaking or separation in storage
Temperature range	-30°C (-22°F) to 70°C (158°F)
Durability	Meet physical properties per MIL-C-12189E (particularly pertaining to Section 4.3.4 - Testing). See also: Fed STD 191 - Textile Test Methods Fed STD 406 - Plastics-Methods of Testing Fed STD 601 - Rubber Sampling & Testing
Odor	No offensive odors
Toxicity	No inherent toxicity hazard
Fabrication Methods	Sewed, glued, heat bonded, impulse heated, sonic bonded, radio frequency bonded or other method to provide leak tight joints. Capable of bonding to other acceptable materials. Seam sealing method lends itself for simple field repairs.

TABLE 1 (continued)

ORIGINAL COAST GUARD ENSEMBLE REQUIREMENTS

Support and Maintenance	Provide data and procedures to sanitize, leak check, seal, repair, inspect, check optical quality, storage requirements
Decontamination	Material does not degrade from decontamination procedures
Material and Production Cost	Material Cost Range $10-$50 per square yard Production Cost Range variable depending upon garment material (max of $1500 per suit)
Chemical Compatibility	Estimated 400 Compounds from CHRIS requiring; encapsulated protection; 100% compatibility desired
Safety Requirements	Impermeable; Fire retardant; Static electricity free

4. Task IV - Laboratory Ensemble Testing.

The objective of this task was to 1) determine the ensemble protection factor, and to 2) conduct manned ensemble performance testing. Protection factor testing was performed to quantitavely measure the effectiveness of the ensemble in protecting the user from a hazardous chemical environment. Manned ensemble performance testing allowed an assessment of ensemble functionally, as well as effectiveness of the body cooling system and the ensemble in terms of comfort and freedom from physical exhaustion.

Portions of this work were earlier reported in an Interim Report published by ILC Dover for the U. S. Coast Guard in November 1982 (authored by Robert Algera of ILC Dover) and a subcontractor report by Arthur D. Little, Inc., entitled, "Chemical Resistance of Three Candidate Materials for the U. S. Coast Guard's Hazardous Chemical Protective Ensemble," (Ref. 3).

CHAPTER 2

CHEMICAL PROTECTIVE MATERIALS SELECTION AND COMPATIBILITY TESTING

In an earlier study, MSA Research Corp. determined that 403 of the CHRIS chemicals would require the use of a totally-encapsulating garment for personnel protection during spill response operations.[2] Their investigation also entailed testing the chemical resistance of primary materials in an initial Coast Guard protective garment design, known as the Hazardous Chemical Protective Clothing Outfit (HCPCO). Butyl rubber and polycarbonate, comprising the garment and visor materials, respectively, were tested against a number of chemicals listed in the Coast Guard's Chemical Hazard Response Information System (CHRIS).[1] Both materials demonstrated limited chemical compatibility for the three hour test period; butyl rubber showed permeation breakthrough for 30% of the chemicals tested whereas polycarbonate was compatible with 60% of the chemicals that require total suit encapsulation. Based on these findings, the Coast Guard recommended identifying materials that would provide protection against those chemicals for which butyl rubber and polycarbonate are incompatible. This was to include chemical compatibility testing of the materials to verify their chemical resistance.

Conclusions from the MSA report and other studies indicated that no one suit material would resist degradation or permeation by all chemicals. Furthermore, nearly all plastic and rubber materials used in chemical protective clothing are permeable to some degree, and for some chemicals there may be no acceptable garment material available to provide adequate protection for the user. Based on this information, the Coast Guard adopted the idea of a "systems" approach in which an inventory of two or more total encapsulating suits constructed of different materials would be employed. Material selections would involve materials with chemical compatibilities for different classes of chemcials to achieve an overall broad chemical resistance of the suit "system". Butyl rubber was selected to be one of the materials in this system. Material selection and compatibility testing were to consider the total ensemble, i.e. if a particular suit material is chemically resistant to a group of hazardous materials, a visor material selected for use with that material should be effective against the same chemicals.

Selection and Screening of Chemical Protective Materials

Research of the chemicals which are not compatible with butyl rubber showed that they fall mainly into the classes of aldehydes, chlorosilanes, ethers, hydrocarbons and inorganic acids. Based on these observations, ILC Dover concentrated its material investigation on finding materials that were resistant to these chemical groups. Considerations were also given to material characteristics such as low temperature performance and cost. Table 2 gives generalized compatibility of several protective clothing materials to a number of different chemical classes. Table 3 summarizes advantages and disadvantages of these materials based on their known physical and operational characteristics. This first phase of the materials search led to the initial

TABLE 2

GENERAL CHEMICAL COMPATIBILITY OF POTENTIAL GARMENT MATERIALS

	Butyl	CPE	Fluorocarbon (Fluorel)	PVC	Polyethylen/Saran	Polycarbonate	PNF	Surlyn 1650 (Ionomer)	Fluorosilicone rubber	Chlorotrifluoroethylene Polymer (KEL-F-81)	Fluorocarbon (FEP)
Aliphatic Hydrocarbons	Poor	Good	Exc	Good	Good	Good	Good to Exc	Good	Exc	Exc	Exc
Aromatic Hydrocarbons	Poor	Poor	Good	Good	Good	Poor	Good to Exc	Good	Good	Exc	Exc
Phenols	Poor	Good	Good	Fair	Good	Fair	Good	Good	Exc	Exc	Exc
Halogenated Hydrocarbons (Partially)	Poor	Poor	Good		Good	Poor	Exc	Fair	Good	Good	Exc
Halogenated Hydrocarbons (Fully)	Poor	Poor	Exc	Poor	Fair	Poor	Good	Fair	Good	Exc	Exc
Ketones	Good	Good	Poor	Poor	Fair	Poor	Poor	Good	Fair to Poor	Exc	Good
Esters	Good	Good	Poor	Fair	Good	Poor	Poor	Good	Fair	Fair	Exc
Monohydric Alcohols	Good	Exc	Exc	Good	Exc	Fair	Poor	Exc	Exc	Exc	Good
Polyhydric Alcohols	Exc	Exc	Exc	Exc	Exc	Good	Good to Exc	Exc	Exc	Exc	Exc
Concentrated Inorganic Acids	Good	Good	Exc	Exc	Exc	Good	Good	Fair	Exc	Exc	Exc
Diluted Inorganic Acids	Good	Exc	Exc	Exc	Exc	Good	Exc	Good	Exc	Exc	Exc
Concentrated Bases	Fair	Exc	Poor	Exc	Exc	Poor	Good	Exc	Exc	Good	Exc
Diluted Bases	Good	Exc	Exc	Exc	Exc	Good	Exc	Exc	Exc	Exc	Good
Concentrated Organic Acids	Fair	Exc	Poor	Exc	Exc	Good	Exc	Good	Good	Good	Exc
Diluted Organic Acids	Good	Exc	Exc	Exc	Exc	Good	Exc	Exc	Exc	Exc	Exc

TABLE 2 (continued)

GENERAL CHEMICAL COMPATIBILITY OF POTENTIAL GARMENT MATERIALS

	Butyl	CPE	Fluoro-carbon (Fluorel)	PVC	Polyethylen/Saran	Polycarbonate	PMF	Surlyn 1650 (Ionomer)	Fluorosilicone rubber	Chlorotrifluoroethylene Polymer (KEL-F-81)	Fluorocarbon (FEP)
Acid Salts	Exc	Exc	Exc	Exc	Exc	Good	Exc	Exc	Exc	Exc	Exc
Neutral Salts	Exc	Exc	Exc	Exc	Exc	Good	Exc	Exc	Exc	Exc	Exc
Basic Salts	Exc	Exc	Exc	Exc	Exc	Fair	Exc	Exc	Exc	Exc	Exc
Concentrating Oxidizing Acids	Poor	Poor	Good	Fair	Fair	Poor	Good to Exc	Exc	Good	Exc	Good
Diluted Oxidizing Acids	Fair	Good	Exc	Exc	Exc	Good	Exc	Good	Exc	Exc	Exc
ASTM #1 Oils	Poor	Exc	Exc	Fair/Good	Fair	N/A	Good to Exc	Good	Exc	Exc	Exc
ASTM #3 Oils	Poor	Good	Exc	Fair/Good	Fair	N/A	Good to Exc	Good	Exc	Exc	Exc
ASTM A Oils	Poor	Good	Exc	Fair/Good	Fair	N/A	Good	Good	Exc	Exc	Exc
Steam	Fair	Poor	Good	Fair/Good	Fair	Poor	Good to Exc	Exc	Exc	Good	Exc
Ozone	Good	Exc	Exc	Exc	Exc	Good	Exc	Fair to Good	Good to Exc	Exc	Exc

TABLE 3

CHARACTERISTICS OF POTENTIAL GARMENT MATERIALS

SUIT MATERIAL CANDIDATES	ADVANTAGES	DISADVANTAGES
Butyl Rubber	Continuous service temperature range from -70° to +400°F. Good abrasion resistance. Low permeability to gases. Good resistance to ketones, esters, most acids and bases, and inorganic salts.	Flexibility at low temperature is good. Poor Resistance to aliphatic, aromatic and halogenated hydrocarbons, phenols and oxidizing acids. Flammable.
Chlorinated Polyethylene (CPE)	Temperature capability range from -40° to +300°F. Good abrasion resistance. Very low permeability to gases. Good to excellent resistance to aliphatic hydrocarbons, phenols, ketones, esters, acids and bases, and salts. Heat sealable. Low cost.	Flexibility at low temperature is fair. Poor resistance to aromatic and halogenated hydrocarbons.
Fluorocarbon - Fluorel/Fluorosilicone	Temperature capability ranges from -63° to +400°F depending on the percentage to which the Fluorel and fluorosilicone are blended. Excellent resistance to hot oils, gasolines, J. P. fuels, and hot corrosive fluids and gases under extreme conditions. Overall good to excellent chemical resistance to hydrocarbons, acids and bases, and salts. Self extinguishing.	Poor chemical resistance to ketones and esters. High cost. Difficulty in manufacturing.
Polyvinyl Chloride	Low temperature flexibility to -40°F. Resistance to amines and aromatics, inorganic acids, bases, and salts. Heat sealable. Low cost.	Poor resistance to halogenated hydrocarbons, ketones and esters.
Polyethylene/Saranex	Provides excellent barrier protection with low permeability to moisture and gases. Excellent resistance to acids and bases and salts. Excellent abrasion resistance and toughness. Heat sealable. Low cost.	Flexibility at low temperatures is fair. Poor resistance to hydrocarbons, phenols and ketones.

TABLE 3 (continued)

CHARACTERISTICS OF POTENTIAL GARMENT MATERIALS

SUIT MATERIAL CANDIDATES	ADVANTAGES	DISADVANTAGES
Chlorotrifluoroethylene - "Kel-F" 81	Operational over wide temperature ranges from -400°F to +400°F. High optical transmittance and low range characteristics. Low permeability to water vapor and gases. Resistant to most organic solvents and oxidants, concentrated acids and strong caustics.	High cost. Difficult to manufacture.
Fluorocarbon - Teflon FEP	Continuous service temperature from -240° to +200°C. Low permeability to liquids, gases, moisture and organic vapors. Excellent chemical resistance to acids, bases and solvents.	Poor resistance to molten alkali metals and certain complex halogenated compounds. High cost. Difficult to manufacture.
Ionomer - Surlyn	Remains flexible at temperatures at -200°F. High tensile and tear strength. Good transparency. Good chemical resistance to oils, gasoline, ketones, and bases. Low cost.	Maximum service temperature is 160°F. Attacked slowly by oxidizing acids.
Polycarbonate	Continuous service temperature range from -150° to +270°F. Good clarity and virtually haze-free. Good resistance to dilute mineral and organic acids, aliphatic hydrocarbons and alcohols.	Attacked by alkaline solutions, ammonia and amines. Soluble in aromatic and chlorinated hydrocarbons and ketones.
Fluorosilicone	Retains flexibility at temperatures as low as -60°F and will not embrittle or melt up to 450°F. Good resistance to oils, gasoline, salts, aliphatic hydrocarbons, ketones, esters, acids, and bases.	Poor resistance to halogenated hydrocarbons. High cost. Difficult to manufacture.
PNF	Temperature serviceability ranges from -65° to +350°F. Excellent resistance to oils and fuels.	Poor resistance to ketones and alcohols. High cost and has not been fully developed for production. Difficult to manufacture.

selection of the following materials for further investigation.

<u>Garment Materials</u>
- Chlorinated Polyethylene (CPE)
- Fluorosilicone
- Fluoroelastomer (Viton)
- Chlorobutyl/Viton laminate
- Fluoroelastomer - Fluorosilicone blend

<u>Visor Materials</u>
- Polyvinyl Chloride
- Fluorinated Ethylene Propylene (FEP)/Surlyn laminate

These materials were then subjected to a screening test program that consisted of physical property testing to determine if the garment could stand up to the rigors of a protective garment application, and swatch testing to compare the basic chemical compatibilities of the candidate materials. Physical property tests included those listed in Table 4. The requirements for passing these tests were established on the basis of Military Specification MIL-C-12189E for butyl coated nylon (previously used in total encapsulating suits). A summary of the physical property results for candidate materials is shown in Table 5. Swatch Testing involved cutting a material sample, subjecting it to a chemical exposure, and observing the results. A detailed description of the procedure is provided in Table 6. Results of this testing for 17 representative chemicals is given in Table 7.

As a result of the screening tests, ILC Dover recommended that a laminate of FEP and Surlyn be used as the visor material for all garments. Chlorinated Polyethylene (CPE) and a laminate of VITON^R and chlorobutyl rubber were recommended as materials to supplement butyl rubber. The FEP/Surlyn was selected based on the excellent chemical resistance of both materials to wide ranges of chemicals. The FEP selected was a .001 in. thick film supplied by Saunders Engineering Co., P/N 100C20. The film has good optical clarity in this thickness in addition to its chemical resistance. Thick FEP would not meet light transmission and haze requirements. Therefore, FEP was laminated to .020 in. thick Surlyn ionomer film supplied by Flex-O-Glass Co., P/N SF71BT (Type 1601). The Surlyn provided an excellent back up to the FEP layer in terms of chemical resistance and met the physical and structural properties required for visor applications.

The VITON/chlorobutyl laminate consisted of 5-7 oz/yd^2 layers of viton and chlorobutyl coated on opposite sides of a 3 oz/yd^2 polyester fabric. This laminate was selected because the chemical resistance of the two materials strongly complement each other. The chlorobutyl is resistant to the polar solvents such as ketones and esters, but it is attacked by the non-polar aliphatic and aromatic hydrocarbons. Conversely the VITON is resistant to non-polar solvents, and is attacked by polar solvents. This combinationprovides versatility through a wide range of chemicals.

The second garment material consisted of two .010 thick layers of CPE laminated on either side of a nylon scrim fabric. The CPE was selected due to its good overall chemical resistance, especially to inorganic acids, and its relatively low cost, both as a raw material and as a finished garment, when

TABLE 4

PHYSICAL PROPERTY SCREENING TESTS

PROPERTY	TEST METHOD	REQUIREMENT
WEIGHT (oz./yd^2)	FED. STD. 191,5041	11 (min.), 20 (max.)
TENSILE STRENGTH (lbs/in) STRIP TENSILE	FED. STD. 191,5102	50 (Warp) (min.), 45 (Fill) (min.)
TEAR STRENGTH (lbs.) (TONGUE)	FED. STD. 191,5134 15 (Fill) (min.)	12 (warp) (min.)
FLEX vs. PINHOLE	Flex 10x, Place in Air Fixture & Check for Bubbles	Pass, No Air Bubbles
FLAMMABILITY	ASTM D568-68	Self Extinguishing
COLD CRACK @ -25°F	ASTM D1790	Pass
COLD TEMP FLEX @ -25°F	ASTM D2136	Pass
ABRASION RESISTANCE H-18 wheel, 1000 cycles	FED. STD. 406,1091	No loose fibers should appear
HYDROSTATIC RESISTANCE (psi)	FED. STD. 191,5512	200 (min.)

TABLE 5

PHYSICAL PROPERTY SCREENING TEST RESULTS OF GARMENT MATERIAL CANDIDATES

PROPERTY	CHLORINATED POLYETHYLENE	FLUOROSILICONE	VITON	VITON/ CHLOROBUTYL	VITON/ FLUOROSILICONE
Weight (oz/yd^2)	19.3	16.0	16.1	15.3	15.8
Tensile Strength (lb/in)	87 (w) 99 (f)	135.5 (w) 86.5 (f)	136 (w) 84 (f)	254 (w) 256 (f)	130 (w) 106.5 (f)
Tear Strength (lb/in)	53.5 (w) 56.7 (f)	13.5 (w) 9.4 (f)	5.8 (w) 4.7 (f)	9.7 (w) 11.0 (f)	15.0 (w) 17.4 (f)
Flex vs. Pinhole	Pass	Pass	Pass	Pass	Pass
Flammability (in/min)	Self-Ext	18	Self-Ext	Self-Ext	24
Cold Crack	Pass at -25°F	Pass at -25°F	Pass at -10°F	Pass at -25°F	Pass at -25°F
Cold Temp Flex	Pass at -25°F	Pass at -25°F	Pass at -25°F	Pass at -25°F	Pass at -25°F
Abrasion (gms lost)	.39	.21	.31	Fibers show at 600 cycles	.72
Hydrostatic Resistance (psi)	200	325	320	385	325

TABLE 6

CHEMICAL SCREENING TEST PROCEDURES

Test Procedure

1. Die cut material samples (1.5" diameter).
2. Wipe off sample with cloth on both sides.
3. Place .25cc of solvent on sample with syringe.
4. Cover solvent drop with cap and weight and allow drop to sit for 5 minutes.
5. Remove cap and blot away excess solvent.
6. Record visual observations about solvent attack.

Chemical List

1. Acetic Acid
2. Acetone
3. Cellosolve Acetate
4. Chloroform
5. Cyclohenanone
6. DMF
7. DMSO
8. Ethanolamine
9. Ethyl Acetate
10. Isoamyl Acetate
11. Isooctane
12. IPA
13. Methylene Chloride
14. MEK
15. Pyridine
16. Toluene
17. Xylene

Materials

1. Chlorinated Polyethylene
2. Fluorosilicone
3. Fluoroelastomer
4. Viton/Chlorobutyl
5. Viton-Fluorosilicone
6. Polyvinyl Chloride
7. FEP/Surlyn

TABLE 7

CHEMICAL SCREENING TEST RESULTS

CHEMICAL	CHLORINATED POLYETHYLENE	FLUOROSILICONE	VITON	CHLOROBUTYL	VITON/ FLUOROSILICONE	POLYVINYL CHLORIDE	FEP/ SURLYN
Acetic Acid (acid)	None	None	None	None	None	Stain	None
Acetone (ketone)	Soften, swell	Soften, swell	Soften	None	Swell Delaminate	Soften	None
Cellosolve Acetate (ester)	None	None	None	None	None	None	None
Chloroform (Chlorinated hydrocarbon)	Swell	None	None	Blister	None	Swell	None
Cyclohexanone (hydrocarbon)	Swell	Soften	Soften	None	Swell Delaminate	Soften Swell	None
DMF (amide)	Soften, swell	Soften	Soften	None	Swell Delaminate	Soften Swell	None
DMSO (sulfoxide)	None	Soften	None	None	Delaminate	None	None
Ethanolamine (amine)	None	None	None	Stain	None	Stain	None
Ethyl Acetate (ester)	Swell	Soften Swell	Soften	None	Swell Delaminate	Swell	None
Isoamyl Acetate (ester)	Swell	Soften Swell	Soften	None	Swell Delaminate	Swell	None
Isooctane (hydrocarbon)	None	None	None	Blister	None	Stain	None

Table 7 (continued)

CHEMICAL SCREENING TEST RESULTS

CHEMICAL	CHLORINATED POLYETHYLENE	FLUOROSILICONE	VITON	CHLOROBUTYL	VITON/ FLUOROSILICONE	POLYVINYL CHLORIDE	FEP/ SURLYN
Isopropyl Alcohol (alcohol)	None	None	None	None	None	None	None
Methylene Chloride (chlorinated hydrocarbon)	None	Soften Swell	None	Blister	Swell Delaminate	Stain	None
Methyl Ethyl Ketone (ketone)	Soften Swell	Soften Swell	Soften	None	Swell Delaminate	Soften Swell	None
Pyridine (amine)	Soften Swell	Soften	None	None	Soften	Soften Swell	None
Toluene (hydrocarbon)	None	None	None	Blister	None	Swell	None
Xylene (aromatic)	None	None	None	Blister	None	None	None
OBSERVATIONS	Attached by hydrocarbons, ketones, and esters	Curling and extreme soften-ing by polar and H-bonded esters and ketones	Softening no severe attack, affected polar and H-bonding solvents, ketones esters	Blistering attack by non-polar, non H-bond-ing solvents, ketones esters	Surface attack by ketones and esters	Attacked by hydro-carbons, ketones, and esters	Resist-ant to all screening chemicals

compared to the VITON/chlorobutyl or butyl materials. As such, it was felt that this material could be used in a large number of the responses to hazardous chemical spills, and thus minimize the overall cost of the Hazardous Chemical Protective Ensemble system.

<u>Compatibility Testing of Chemical Protective Materials</u>

Arthur D. Little, Inc., under subcontract to ILC Dover, evaluated the chemical resistance of the three selected materials for the new Hazardous Chemical Protective Ensemble. Chemical compatibility was tested using two procedures:

1) Immersion Testing - involving the determination of changes in weight and elongation (under a dead load) of the selected materials following a three-hour, single-sided immersion in each chemical.

2) Permeation Testing - involving the determination of the amount of chemical which permeated the selected materials in three hours, and the time the chemical was detected to "break through" the material sample.

The three hour exposure time was selected to be consistent with the intended maximum wear time for the totally-encapsulating suit. Additional chemical resistance testing entailed evaluating several seam constructions for chemical resistance and investigating a detergent/water washing decontamination method of selected materials.

<u>Selection of Chemicals for Testing</u>. The U.S. Coast Guard reevaluated MSA Research Corps findings and selected 199 chemicals to be included in this study. The criteria for choosing these chemicals included:

1) chemicals that severely attacked both butyl rubber and polycarbonate.

2) chemicals that had moderate effects on one of the materials (usually the polycarbonate) and severe effects on the other material (usually the butyl rubber).

3) chemicals having high interstate volumes of sales.

4) chemicals which are or are thought to be particularly hazardous to human health.

A listing of these chemicals (alphabetical by the CHRIS three letter Code) is presented in Appendix A. NOTE: CHRIS codes are employed in some sections of the text in lieu of chemical names.

Of the selected chemicals, one hundred and forty eight chemicals were acquired in technical or better grades from the usual laboratory supply houses. The 12 pesticides in the listing were obtained in the form of liquid concentrates directly from their manufacturers. All the concentrates, except Diuron, were based on xylene, naptha, or some other petroleum distillate; Diuron was water-based. Generally, the most common liquid solvent for the pesticide was chosen. The remaining 39 chemicals were not acquired for a variety of reasons as itemized below:

1) Six aldehydes (BAD, BTR, DAL, EHA, HAL, IDA) - The listing of 199 contained 13 aldehydes; it was concluded that the testing of seven chemicals of this class would be adequate.

2) Six chlorosilanes (ATS, BCS, CHT, DTC, ECS, EPS) - The listing of 199 chemicals included 14 chlorosilanes; it was concluded the testing of eight chemicals of this class would be sufficient.

3) Thirteen chemicals due to cost (BTF, APF, BEC, BPF, CTF, FXX, MFA, CMS, NTC, MPD, PDL, TEL, TML) - Many of these chemicals are highly reactive and form hydrogen fluoride or hydrogen chloride (or their acids) upon contact with air. Since these reaction products were already included in the listing of 199, it was concluded that little or nothing would be lost by omitting these costly chemicals. The MFA, TEL, and TML are lead alkyls. Their cost from a chemical supply house was extremely high (on the order of $1500 per 100 grams). In lieu of performing the chemical resistance tests for these substances, the subcontractor searched the literature for information pertinent to protective clothing for lead alkyls. Their finding was that both neoprene and nitrile rubbers were preferred for use with lead alkyls.

4) Eight insoluble and unreactive solid chemicals (CAS, DNZ, DNB, NTA, PCP, TPH, CNO, DCP) - For the purposes of this study, it was concluded that there was little to be gained by testing chemicals that would inertly sit on the surface of the candidate materials.

5) Liquid sulfur (SXX) - The principal hazard of liquid sulfur is its heat. Thermal protection was not a requirement for the ensemble to be developed in this program.

6) Oleum (OLM) - Concentrated sulfuric acid (SFA) and 50% sulfuric acid (SAC) were tested.

7) Three chemicals for which we found no source (DZP, TED and TEB).

The types of testing performed with each selected chemical, if any, is indicated in Appendix A.

Material Samples. All material samples were supplied to Arthur D. Little, Inc., by ILC Dover. Detailed descriptions of these materials are given below:

VITON/Chlorobutyl Laminate: Polyester fabric (3 oz/yd^2) is coated on one side with 5-7 oz/yd^2 VITON fluoroelastomer (orange) and the other side with 5-7 oz^2 chlorobutyl rubber (gray). The total thickness was 0.014 inch. The VITON side was designated as the external or chemical-facing side.

Chlorinated Polyethylene: Nylon scrim (3 oz/yd^2) is supported with 10 mil chlorinated polyethylene (Chloropel) on each side. Total thickness was 0.020-0.024 inch, and the color was white. Immersion testing was also performed with 0.020 inch and 0.030 inch unsupported Chloropel.

FEP/Surlyn Laminate: FEP film laminated to Surlyn. The FEP film was 0.001 inch in thickness while the thickness of the laminate ranged from 0.17 to 1.24 inch. The FEP side faced the chemical.

Immersion Testing

Procedure. The first step in evaluating the compatibility of the materials and seams with the chemicals was the immersion test. In the test, only the normally outside surface of the material or seam was exposed to the chemical. In the case of the VITON/chlorobutyl rubber material, the VITON surface faced the chemical; while with the FEP/Surlyn, the FEP film faced the chemical. The Chloropel material was the same on both sides. The exposure duration was three hours.

At the end of the exposure, a four-inch long ASTM D412 Die C specimen (with one-quarter inch neck) was cut from the center of the material. The specimen was promptly weighed and then subjected to the elongation test. The elongation test simply involved suspending a five-pound load from one end of the specimen and noting the length to which the specimen extended in 5 seconds. (This was not a creep test.) The percentage differences between the weight and extensions of unexposed (i.e., control) Die C shaped specimens and the exposed specimens were then calculated. The results are reported as percentage change from original.

Apparatus. Immersion testing with the liquid chemicals was conducted using fixtures designed and fabricated specifically for this study. A sketch of the device is shown in Figure 1. The apparatus was composed of a plastic, two-piece exposure chamber and a clamping mechanism. Into one piece of the chamber was milled a 5.5-inch long x 1-1/4-inch x 3/8-inch deep trough. Around the perimeter of the trough was an O-ring. The other piece of the chamber (the cover) was a smooth, plastic rectangle that was fastened to the clamping mechanism.

In practice about 5 cm^3 of the chemical was placed in the trough. A 2 x 7-inch swatch of the material to be tested was placed (outside surface down) over the trough. The two pieces of the apparatus were clamped together, thereby compressing the O-ring and sealing the chemical in the chamber. The chamber was then turned upside down and placed in a storage rack for three hours. After the exposure period, the material was removed from the apparatus and a Die C specimen cut from its center. The specimen was immediately weighed and evaluated for elongation and described above.

19 test chambers were fabricated: 15 were fabricated from high density polyethylene and 4 were made of TEFLON. Both VITON and EPR O-rings were used. The principal reason for using a plastic rather than a glass chamber was that the chemical reservoir could be machined to dimensions that minimized the amount of chemical required to cover the entire ASTM Die C specimen. The objective was to minimize the amounts of chemicals handled in the study for safety reasons. The built-in clamping mechanism also contributed to safe as well as efficient experimentation. At the end of a test, the entire device

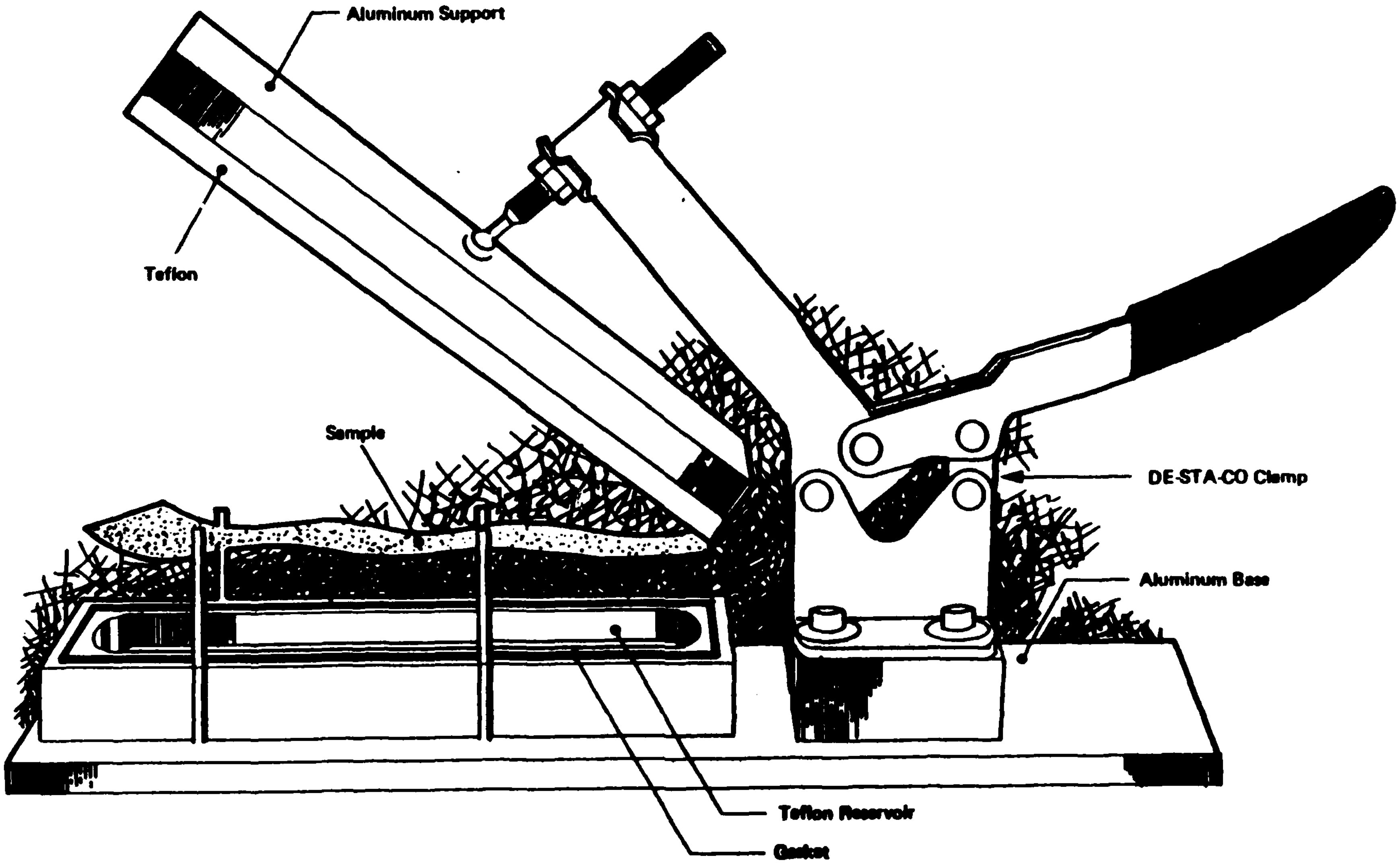


FIGURE 1. SINGLE-SIDED IMMERSION TEST CELL FOR LIQUID CHEMICALS

could be immersed in a neutralizing bath in order to decontaminate it of chemical in preparation for the next test.

The list of 199 chemicals included 12 gases. Immersion testing with these was single-sided, with weight and elongation changes again of interest. The apparatus is illustrated in Figure 2. The chamber was simply an X-section of 2-inch diameter glass pipe. The three test materials were clamped across three of the openings of the "X" and the gas inlet and exit were at the fourth opening. A 2-inch diameter area of the material was exposed to the gas. The Die C specimen for weight and elongation measurements was cut from the center of this area such that its 1-1/4-inch long neck section had been entirely exposed to the gas. The gas flowed through the chamber for the entire three-hour period.

Results. Each of the three candidate materials were subjected to immersion testing with the 160 chemicals. These findings are summarized in Table 8 in terms of percentage changes in weight and elongation (under 5-pound load) from those of unexposed specimens. In cases where the Die C specimen broke under the 5-pound load, the elongation is reported as "F" for failure.

The table also includes a comment column for each material. Observations of appearance changes in the materials are reported using codes. The right-most column of the table contains general comments pertaining to the chemical. The footnotes to the table elaborate on the abbreviations in the comments column.

Overall observations are:

1) The FEP/Surlyn exhibited excellent resistance to virtually all 160 chemicals. The exceptions were acrolien (ARL), n-butyl amine (BAM), di-n-butyl amine (DBA), and methyl acrylate (MAM). The subcontractor also noted slight curling of the material after its exposure to iso-propyl ether (IPE) and trimethylamine water solution (TMA). Finally, upon exposure to fluosulfonic acid (FSA), the FEP/Surlyn developed several small dark spots. This may have been an indication of pinholes in the FEP film.

2) For the VITON/chlorobutyl rubber, the weight changes were less than 10% and there was no noticeable change in appearance or elongation for 119 of the 160 chemicals. The material was degraded by three chemicals - butyl amine (BAM), isobutyl amine (IAM), and propylamine (PRA) - to the point that elongation tests could not be performed. The material failed the elongation test after exposure to fluosulfonic acid (FSA). For the remaining 37 chemicals, there was a varying level of reaction, as indicated in Table 8.

3) Seventy-one chemicals caused the failure of the chlorinated polyethylene under elongation testing. For 29 additional chemicals, the percentage weight change of the material was greater than 10%.

4) In all, twenty-two of the chemicals were in the form of aqueous solutions; none had a significant effect on any of the materials.

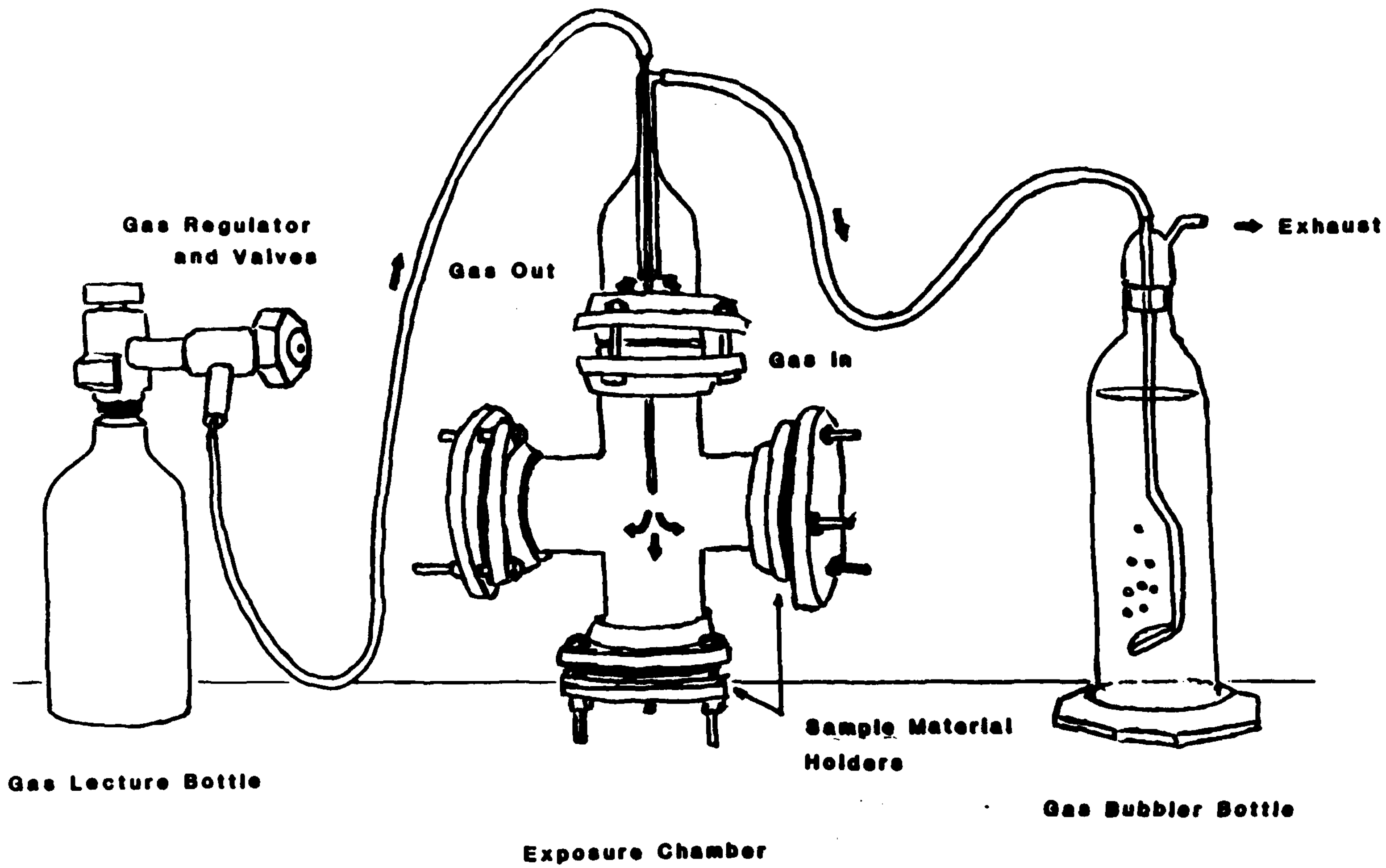


Figure 2. Single-Sided Immersion Cell for Gaseous Chemicals

TABLE 8

SUMMARY OF RESULTS OF IMMERSION TESTING

	VITON/CHLOROBUTYL			FEP/SURLYN			CHLOROPEL			
CHRIS CODE	% WT. INCR.	% ELONG.	COMMENT	% WT. INCR.	% ELONG.	COMMENT	% WT. INCR.	% ELONG.	COMMENT	GENERAL COMMENTS
AAD	10	0		0	-5		24	11		
ABM	29	6		0	0		142	F		
ACC	20	0	BDEG	-2	0		72	F		
ACF	-2	0		-1	0		7	0	COLDAR	
ACL	-5	0		-1	0		1	0		50% AQUEOUS
ACN	9	0	C,DELAM	-1	0		35	F		
ADN	-2	0		-1	0		5	0		
ALA	1	0		0	0		2	11		
ALC	1	0		-1	0		238	F	DELAM	
APC	1	0		1	0		3	0		
ARL	8	0	SC	13	33	C	35	F		
ASC	1	0		-3	-6		61	0	C	
ASU	-3	0		0	0		1	0		50% AQUEOUS
ATC	1	0		NT	NT	INSUFCEM	49	F		
ATM	-5	0		-2	0		1	0		10% AQUEOUS
BAM	100		VDEG	11	33		8	0		
BBR	-4	0		-3	0		126	F		
BCL	-2	0		-3	0		118	F		
BCY	-2	0		-1	0		2	0		50% AQUEOUS
BDE	1	0		-1	0		3	0		
BEN	-6	0		-1	0		2	0		50% AQUEOUS
BNZ	2	0		0	0		60	F		
BPT	-4	0		-4	-5		64	0		
BRM	0	0		-2	0		276	F		
BRT	3	0		0	0		2	0	COLDAR	
BTB	4	0	COLDAR	-1	0		122	0		
BTO	28	6	C	-2	0		63	F		
CAC	4	0		0	0		177	F		
CBB	-5	0		-1	0		33	F		
CBO	-1	0		-1	0		13	0		
CBR	1	0		0	0		13	0		SAT. AQUEOUS
CCL	7	0		0	0		15	6	COLDAR	
CDN	-3	0		-1	0		8	0		PESTICIDE AQUEOUS
CES	2	0		1	0		0	0		
CHA	27	0	HC	11	0		73	F		
CLX	1	0	COLLIT	0	0		3	0		
CMA	-2	0		-1	0		1	0		50% AQUEOUS
CME	22	0	SC	-1	0		101	F		
CMH	1	0		2	0		22	6		
COU	3	0		0	0		42	F		PESTICIDE
CPL	6	0	SC	-2	-5		173	F		
CRF	4	0		0	0		72	F		
CRP	-5	0		-2	0		91	F		50% IN XYLENE
CSA	43	0	C	-1	0		48	0	CPEDEG	
CTA	8	0	C	-1	0		41	F		
CTD	-4	0		-2	0		70	6		

Arthur D. Little, Inc.

TABLE 8

SUMMARY OF RESULTS OF IMMERSION TESTING

CHRIS CODE	VITON/CHLOROBUTYL % WT. INCR.	VITON/CHLOROBUTYL % ELONG.	VITON/CHLOROBUTYL COMMENT	FEP/SURLYN % WT. INCR.	FEP/SURLYN % ELONG.	FEP/SURLYN COMMENT	CHLOROPEL % WT. INCR.	CHLOROPEL % ELONG.	CHLOROPEL COMMENT	GENERAL COMMENTS
CUM	-1	0		0	0		57	F		
DAC	31	0	NC	-6	0		95	F		
DBA	-6	0		10	22		12	11		
DBO	-1	0		0	0		80	F		
DCB	-1	0		-1	0		161	F		
DCV	4	0		0	0		76	F		PESTICIDE
DDB	2	0		1	0		2	0		
DEE	2	0		-7	0		63	F		
DFA	-1	0		-2	0		11	0	COLDAR	
DIH	2	0		0	0		12	0		
DIS	0	0		0	0		24	0		PESTICIDE
DIU	-1	0		-1	0		3	0		PESTICIDE, AQUEOUS
DMD	0	0		-1	0		44	F		
DNA	0	0		2	0		24	F		
DPD	-3	0		-1	0		22	0		
DPP	3	0		-2	0		120	F		
DSL	11	0	BUTWET	-1	0		91	F		
DTN	2	0		0	0		27	F		PESTICIDE
DUR	3	0		0	0		55	F		PESTICIDE
EAC	17	0	C	0	0		160	F		
EAI	8	0	SC	-1	0		34	6		
EAM	30	0	C, COLDAR	-4	-5		11	6		
ECF	22	0	C	0	0		94	F		
EDB	0	0		1	0		187	F		
EDC	2	0		-2	0		147	F		
EDR	-3	0		0	0		59	F		PESTICIDE
ENB	-5	0		-1	0		17	11		
EOX	2	0		0	0		13	11		
EPD	-2	0		-2	0		115	F		
EPP	48	0	NC	0	0		93	F		
ESF	1	0		-2	0		57	F		PESTICIDE
ETC	6	0		-5	0		2	0		
ETH	29	0	NC	1	0		87	F		
ETO	1	0		0	0		21	F		PESTICIDE
ETS	-3	0		-1	0		38	11		
FCL	-4	0		-1	0		2	6		50% AQUEOUS
FFB	0	0		-1	0		1	0		
FMS	0	0		-1	0		0	0		40% AQUEOUS
FSA	111	F		1	0	PINHOLE	84	F		
FSL	-3	0		-1	0		1	0		32% AQUEOUS
GTA	-3	0		0	0		1	0		50% AQUEOUS
HBR	2	0	COLDAR	-1	0		6	0	COLDAR	
HCL	8	0	COLDAR	-4	0		1	0		53% AQUEOUS
HCN	0	0		0	0		0	0		
HDC	3	0	COLDAR	-1	0		0	0	COLDAR	
HFA	2	0	COLLIT	0	0		6	0		52% AQUEOUS

TABLE 8

SUMMARY OF RESULTS OF IMMERSION TESTING

CHRIS CODE	VITON/CHLOROBUTYL % WT. INCR.	VITON/CHLOROBUTYL % ELONG.	VITON/CHLOROBUTYL COMMENT	FEP/SURLYN % WT. INCR.	FEP/SURLYN % ELONG.	FEP/SURLYN COMMENT	CHLOROPEL % WT. INCR.	CHLOROPEL % ELONG.	CHLOROPEL COMMENT	GENERAL COMMENTS
HFX	4	0		4	0		2	11		IN AIR VDEG & CPEDEG
HMI	18	0	C	-4	0		60	F		
HMT	0	0		0	0		0	0		50% AQUEOUS
IAI	0	0		3	0		20	0		
IAM	106		VDEG	-1	0		54	F		
IBN	16	0	NC	-3	0		36	F		
IOC	-1	0		-3	0		3	0		
IPE	8	0		1	0	SC	3	0		
IPM	1	0		0	0		78	F		
IVA	18	0	C	2	0		101	F		
LPM	-3	0		0	0		10	0		
MAM	13	0	C	8	28	SC	57	F		
MCH	23	0	C	0	0		85	F		
MCS	4	0		-3	-5		53	F		
MPY	31	11	NC	-2	0		100	F		
MSO	29	6	NC	-1	0		130	F		
MTB	8	0		1	0		19	0		
MTS	4	0		-3	0		54	0		
MVK	19	6	C,BUTWET	-1	0		82	F		
NAA	-2	0		-2	0		1	0		SAT. AQUEOUS SALT
NAC	9	0	COLLIT	0	0		8	-6		
NCT	2	5		0	0		81	F		
NIC	1	0		8	22		64	F		
NIE	2	0		-1	0		114	F		
NOX	2	0	COLLIT	1	0		10	0		
NSV	-5	0		0	0		2	0		
NTB	2	0		-4	0		135	F		
NTX	5	0	COLLIT	-1	0		5	0		
OXA	3	0		-1	0		2	0		SAT. AQUEOUS
PAA	10	0	COLLIT	-1	0		4	0		40% IN ACETIC ACID
PBR	1	0		-3	0		107	F		
PCB	3	0		-1	0		-6	0		PCB IN HYDRAL. OIL
PCM	0	0		-1	0		86	F		
PHG	5	0		4	0		6	0		
PHN	-3	0		-3	0		5	0		SAT. AQUEOUS
PMN	-1	0		0	0		57	F		
PPO	61	0		-1	0		232	F		
PPT	0	0		0	0		128	F		
PRA	53		VDEG	1	0		72	F		
PTL	3	0		-1	0		-2	0		
SAC	-5	0		0	0		0	0		50% AQUEOUS
SCL	56	0	C,BDEG	-2	0		168	F		
SDS	2	0		0	0		1	0		SAT. AQUEOUS
SFA	2	0		-1	0		16	0	COLDAR	
SFD	3	0		2	0		4	0		
SFM	-3	0		-2	0		182	F		

TABLE 8

SUMMARY OF RESULTS OF IMMERSION TESTING

CHRIS CODE	VITON/CHLOROBUTYL % WT. INCR.	VITON/CHLOROBUTYL % ELONG.	VITON/CHLOROBUTYL COMMENT	FEP/SURLYN % WT. INCR.	FEP/SURLYN % ELONG.	FEP/SURLYN COMMENT	CHLOROPEL % WT. INCR.	CHLOROPEL % ELONG.	CHLOROPEL COMMENT	GENERAL COMMENTS
STC	4	0		-4	0		9	0		
STR	-1	0		-1	-5		3	0		SAT. AQUEOUS
TAP	-4	0		-1	0		1	0		AQUEOUS
TCL	0	0		-1	0		145	F		
TDI	-1	0		-1	0		56	F		
TEC	1	0		1	0		206	F		
TEN	1	0		0	0		8	11		PESTICIDE
TES	1	6		-1	0		3	0	C	
THF	45	0	C,DELAM	-1	0		122	F		
THA	-2	0		3	0	SC	-1	0		AQUEOUS
THC	0	0		0	0		9	11		
TPG	2	0		-2	-5		126	F		
TTT	-1	0		-1	0		14	0	STIFFEN	
TXP	-1	0		3	0		6	0		PESTICIDE
VCI	2	0		-2	0		90	F		
VCM	6	0		0	0		5	0		
VFI	3	0		0	0		2	0		
VIS	-3	0		0	-5		56	11		
ZCL	-3	0		-4	0		3	0		SAT. AQUEOUS
ZCT	-5	0		-1	0		2	0		SAT. AQUEOUS
ZFB	1	0		-1	0		0	0		
ZPF	-1	0		0	0		0	0		SAT. AQUEOUS

FOOTNOTES: AQUEOUS=TEST CHEMICAL WAS IN AN AQUEOUS SOLUTION. CONCENTRATION IS REPORTED AS WEIGHT PERCENT.

BDEG=BUTLY DEGRADED.

BUTWET=VITON INTACT. BUTYL APPEARED WET.

C=MATERIAL EXHIBITED MODERATE CURLING AFTER EXPOSURE.

COLDAR=MATERIAL DARKENED IN COLOR.

COLLIT=MATERIAL LIGHTENED IN COLOR.

CPEDEG=CHLOROPEL DEGRADED.

DELAM=DELAMINATION.

HC=MATERIAL EXHIBITED SEVERE CURLING AFTER EXPOSURE.

INSUFCEM=INSUFFICIENT CHEMICAL.

NONUNIF=MAY HAVE BEEN FLAW IN MATERIAL.

NT=NOT TESTED.

PCB IN HYDRAULIC WAS OF UNKNOWN CONCENTRATION.

SC=MATERIAL EXHIBITED SLIGHT CURLING AFTER EXPOSURE.

VDEG=MATERIAL SEVERELY DEGRADED. ELONGATION NOT PERFORMED.

WEIGHT CHANGES LESS THAN 5% AND ELONGATIONS LESS THAN 8% ARE NOT SIGNIFICANT

5) Twelve pesticide formulations were evaluated. None had a measurable effect on the VITON/chlorobutyl rubber or the FEP/Surlyn. However, large weight increases or elongation failures occurred with the Chloropel with eight of the pesticides.

Additional Immersion Testing

The findings reported above were for 0.02-inch thick scrim supported Chloropel. ILC Dover speculated that the poor performance of the scrim supported CPE may have been the result of a "wicking" process in which the fabric support absorbed chemical permeating the outer layer and became weakened as a result (contributing to the large number of elongation test failures). Because of the relatively high number of failures, additional testing was conducted with 15 chemicals using 0.02-inch and 0.03-inch unsupported Chloropel. In part of this additional test series, supported and unsupported 20 mil materials were compared. The scrim supported material was included as a control and as a means for determining the reproducibility of the method. Results for this testing with 10 chemicals are presented in Table 9 (The right-most column of the table repeats the data from Table 8, for convenient comparison of the results of the two test series). For an different 5 chemicals, weight and elongation changes were determined at several different times over the three-hour period with the objective of estimating the rates at which the chemicals attacked the Chloropel. These results appear in Table 10.

Overall, the results of the two studies were in remarkably good agreement. Exceptions to this generalization were the results for coumaphos (COU), 4-chloro-o-toluidine (CTD), and nicotine (NIC). In these cases the weight changes were similar in both studies; but the results of the elongation tests differ. A. D. Little, Inc. suspected this is due to variability in the amount of scrim included in the strength test specimens due to its open mesh construction. From the results for the five chemicals for which measurements were taken over the three-hour period, it is seen that sorption of the chemicals is rapid. In six cases there were failures under the five-pound load after only 15 minutes' exposure to the chemicals. In several other cases, the elongation was well above that which could be considered acceptable. In fact, taken together, the elongation and weight change results seem to suggest that none of the Chloropel materials would be an effective, 15-minute barrier to Acrolein (ARL), Acrylonitrile (ACN), Methyl Acrylate (MAM), Methyldichlorosilane (MPY), or Toluene-2,4-Diisocyanate (TDI). A final observation is that, as expected, for an equivalent or lesser weight change the unsupported material undergoes a significantly greater elongation than does the scrim-supported material.

Permeation Testing

Procedures and Apparatus. Due to cost and time constraints, permeation testing was limited to approximately 60 chemicals. The list of 160 chemicals was organized in chemical reactivity classes. Representative chemicals were chosen from each class for permeation testing (see Table 11). In addition to the permeation tests with CHRIS chemicals, the three materials were also

TABLE 9

COMPARISON OF 20 MIL THICK SCRIM SUPPORTED AND UNSUPPORTED
CHLORINATED POLYETHYLENE IMMERSION TESTING

Chemical	Material[1]	New Study Wt.	New Study Elong[2]	Prev Study Wt.	Prev Study Elong
Carbon Disulfide	20sc	55	F	33	F
	20us	34	F		
Chloroform	20sc	161	F	72	F
	20us	69	F		
Coumaphos	20sc	59	22	42	F
	20us	33	156		
Crotonaldehyde	20sc	35	F	41	F
	20us	26	F		
4-Chloro-o-toludine	20sc	61	F	70	6
	20us	37	F		
Dimethyl Dichlorosilane	20sc	44	F	44	F
	20us	19	179		
Demeton	20sc	44	F	27	F
	20us	32	F		
Isobutronitrile	20sc	40	F	36	F
	20us	21	F		
Naptha, Coal tar	20sc	93	F	81	F
	20us	27	F		
Nicotine	20sc	57	0	64	F
	20us	43	156		

---

[1] 20sc: 20 mil thick serum supported CPE; 20us: 20 mil thick unsupported CPE
[2] F: Failed under 5 lb (20 lb/in.) load

TABLE 10

RESULTS OF ONE SIDED IMMERSION TESTING FOR THREE FORMS OF CHLORINATED POLYETHYLENE OVER TIME

Chemical	Material	0.25 hr		0.5 hr			0.75 hr		1 hr		2 hr		3 hr	
		Wt	Elong	Wt	Abs	Elong	Wt	Elong	Wt	Elong	Wt	Elong	Wt	Elong
Acrolein	20sc	17	F	29	0.367	F	29	F	39	F	NT		NT	
	20us	13	F	16	0.206	F	20	F	21	F	NT		NT	
	30us	10	74	17	0.336	175	17	275	15	F	NT		NT	
Acrylonitrile	20sc	17	F	20	0.251	F	24	F	22	F	NT		NT	
	20us	13	F	15	0.183	F	15	F	19	F	NT		NT	
	30us	9	119	10	0.200	119	7	231	12	253	17	242	NT	
Methyl Acrylate	20sc	32	F	49	0.623	F	53	F	58	F	NT		NT	
	20us	29	F	25	0.313	F	28	F	28	F	NT		NT	
	30us	15	97	22	0.433	197	25	320	26	F	NT		NT	
1-Methylpyrolidone	20sc	24	0	41	0.517	0	54	F	43	F	90	F	87	F
	20us	19	89	47	0.591	201	63	F	43	F	81	F	65	F
	30us	10	63	31	0.613	86	47	74	52	74	62	F	62	F
Toluene Diisocyanate	20sc	18	0	31	0.397	0	32	6	40	0	40	F	70	F
	20us	10	45	19	0.243	56	20	78	24	78	24	201	43	F
	30us	5	19	10	0.195	30	13	41	16	30	17	41	29	52

1 20sc: 20 mil thick scrim-supported CPE; 20us: 20 mil thick unsupported CPE; 30us: 30 mil thick unsupported CPE
2 F: Failed under 5 lb (20 lb/in) load
3 Abs: actual weight (grams) absorbed by CPE specimen
4 NT: Not Tested

subjected to testing with Freon 12. Freon 12 was originally intended for use as the tracer gas in the protection factor testing of prototype ensembles.

Permeation testing was conducted using a method which subsequently became ASTM F739-81, "Standard Test Method for Permeation Resistance of Protective Clothing Materials to Liquid Chemicals." In this procedure, a 2-inch diameter area of the test material is continuously exposed to the chemical - liquid or gas - for the duration of the test. The duration of the test was three hours. A diagram of the apparatus appears in Figure 3. Both the total amount of chemical that permeated each material over the three hours and the breakthrough time were measured. Breakthrough time is the time at which the chemical is first detected in the collection side of the permeation cell.

The ASTM Method does not specify a means for detecting the chemical. The principal analytical instrument used to monitor permeation was a Miran 80A (Foxboro, Inc.). This instrument was used for virtually all (organic) chemicals having appropriately high vapor pressures at room temperature. Air from the collection side of the cell was continuously circulated through the Miran, which measures the infrared absorbance of the chemical vapor. The instrument was calibrated for each chemical by first determining its wavelength of maximum infrared absorbance and then injecting known amounts of chemicals into the air stream. In cases where high levels of permeation occurred, the system was modified from a recirculating flow pattern to a single pass system.

Other analytical methods were:

1) Atomic absorption for metal-containing compounds.

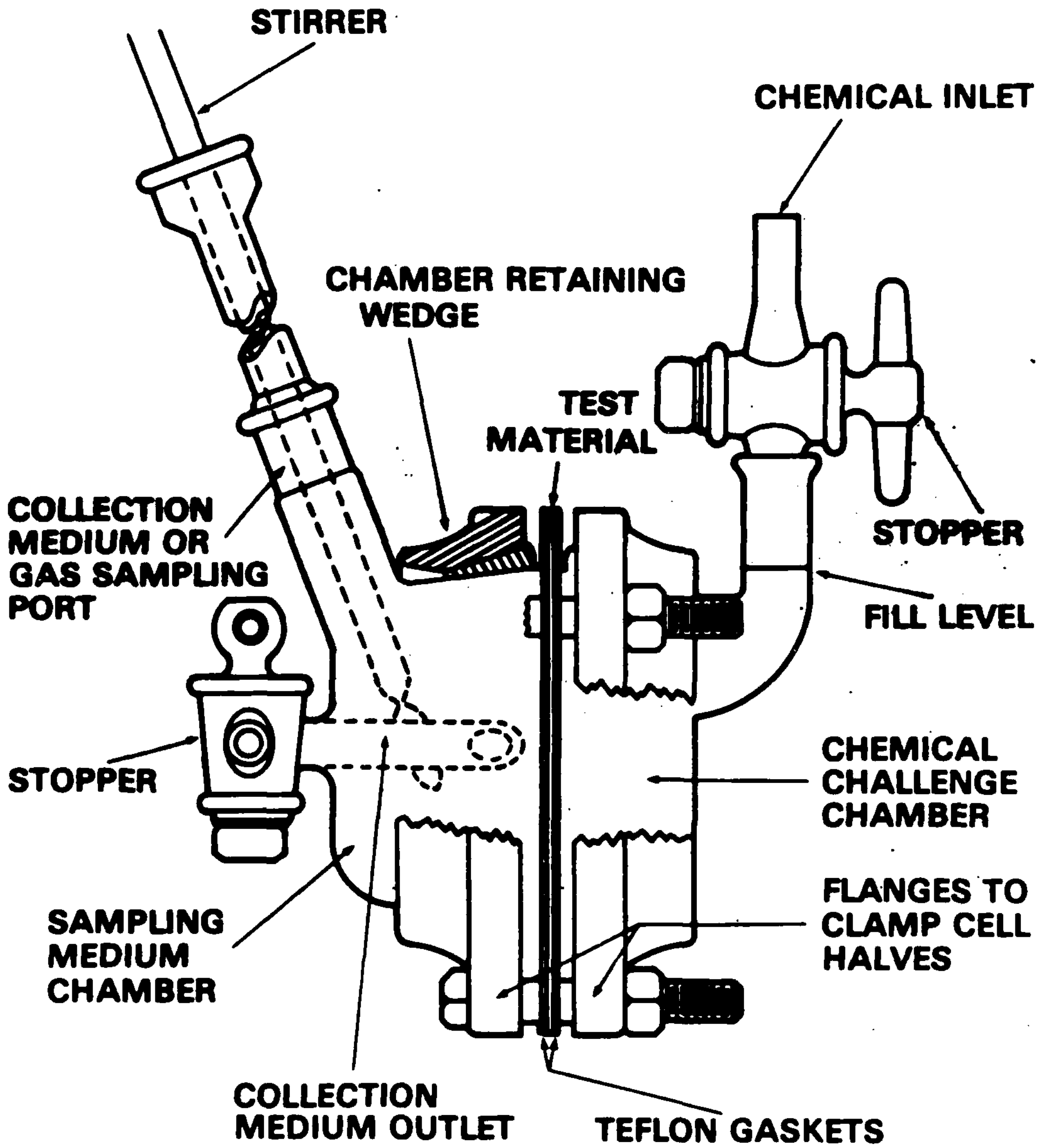
2) Ion chromatography for the acids, halogen-containing gases and chlorosilanes.

3) Scintillation counting for organic compounds having low vapor pressures and available in radiolabeled form.

4) Gas chromatography for organic compounds having low vapor pressures but not available in radiolabeled form.

The sensitivity of the analytical method varied from chemical-to-chemical and was dependent on the analytical method.

Results. The three selected materials were subjected to permeation testing with 56 CHRIS chemicals, plus Freon 12. The results are reported in Table 11 as the mass flux of chemical for a three hour period. In Table 12, permeation breakthrough times are given for each selected material. "NBT" indicates that no permeation was detected in three hours. Since detection was dependent on the sensitivity of the analytical method and since the sensitivity varied from chemical to chemical, the detection methods and sensitivities are also reported in Table 12. The sensitivity is reported in terms of the minimum number of milligrams of chemical that would have had to permeate a square meter of material in three hours in order to be detected. Table 13 gives the distribution of breakthrough times for each material. There was no detectable permeation of Freon 12 through any of the materials in



PERMEATION TEST CELL

Figure 3

TABLE 11

SUMMARY OF RESULTS OF PERMEATION TESTING

	VITON/CHLOROBUTYL				FEP/SURLYN				CHLOROPEL				
CHRIS CODE	%WT INCR.	% ELONG.	3-HOUR PERMEATION GM PER SQ.M	COMMENT	%WT INCR.	% ELONG.	3-HOUR PERMEATION GM PER SQ.M	COMMENT	%WT INCR.	% ELONG.	3-HOUR PERMEATION GM PER SQ.M	COMMENT	GENERAL COMMENTS
ACN	9	0	.17	C,DELAM	-1	0	N.D.		35	F	49.00		
ALA	1	0	N.D.		0	0	N.D.		2	11	.15		
ALC	1	0	50.00		-1	0	N.D.		238	F	2300.00	DELAM	
BAM	100		1400.00	VDEG	11	33	N.D.		8	0	3470.00		
BCL	-2	0	N.D.		-3	0	N.D.		118	F	200.00		
BCY	-2	0	N.D.		-1	0	N.D.		2	0	N.D.		50% AQUEOUS
BEN	-6	0	N.D.		-1	0	N.D.		2	0	N.D.		50% AQUEOUS
BNZ	2	0	N.D.		0	0	N.D.		60	F	800.00		
BPT	-4	0	N.D.		-4	-5	N.D.		64	0	N.D.		
BTO	28	6	330.00	C	-2	0	N.D.		63	F	2400.00		
CBB	-5	0	N.D.		-1	0	N.D.		33	F	2424.00		
CBO	-1	0	N.D.		-1	0	N.D.		13	0	N.D.		
CHA	27	0	.15	HC	11	0	N.D.		73	F	162.00		
CRF	4	0	.01		0	0	N.D.		72	F	4000.00		
CTA	8	0	.15	C	-1	0	N.D.		41	F	1743.00		
CTD	-4	0	N.D.		-2	0	N.D.		70	6	N.D.		
CUM	-1	0	N.D.		0	0	N.D.		57	F	89.00		
DAC	31	0	N.D.	HC	-6	0	N.D.		95	F	563.00		
DBA	-6	0	N.D.		10	22	N.D.		12	11	N.D.		
DBO	-1	0	N.D.		0	0	N.D.		80	F	N.D.		
DCB	-1	0	N.D.		-1	0	N.D.		161	F	609.00		
DDB	2	0	N.D.		1	0	N.D.		2	0	N.D.		
DEE	2	0	N.D.		-7	0	N.D.		63	F	108.00		
DMD	0	0	N.D.		-1	0	N.D.		44	F	N.D.		
DPP	3	0	N.D.		-2	0	N.D.		120	F	702.00		
EAC	17	0	28.00	C	0	0	N.D.		160	F	500.00		
EAI	8	0	N.D.	SC	-1	0	N.D.		34	6	N.D.		
EDB	0	0	N.D.		1	0	N.D.		187	F	1051.00		
EDC	2	0	N.D.		-2	0	N.D.		147	F	1250.00		
ETC	6	0	N.D.		-5	0	N.D.		2	0	N.D.		
ETM	29	0	63.00	HC	1	0	N.D.		87	F	360.00		
FMS	0	0	N.D.		-1	0	N.D.		0	0	N.D.		40% AQUEOUS
HCL	8	0	N.D.	COLDAR	-4	0	N.D.		1	0	N.D.		53% AQUEOUS
HDC	3	0	N.D.	COLDAR	-1	0	N.D.		0	0	N.D.	COLDAR	
HMI	18	0	N.D.	C	-4	0	N.D.		60	F	6.00		
IBN	16	0	N.D.	HC	-3	0	N.D.		36	F	197.00		
IOC	-1	0	N.D.		-3	0	N.D.		3	0	N.D.		
IPE	8	0	N.D.		1	0	N.D.	SC	3	0	N.D.		
IVA	18	0	25.00	C	2	0	N.D.		101	F	616.00		
MSO	29	6	26.00	HC	-1	0	N.D.		130	F	2800.00		

N.D. INDICATES THAT NO PERMEATION WAS DETECTED AFTER THREE HOURS.
DETECTION LIMITS ARE LISTED IN TABLE 4.
SEE TABLE 1 FOR EXPLANATION OF ABBREVIATIONS IN COMMENT COLUMNS.

TABLE 11

SUMMARY OF RESULTS OF PERMEATION TESTING

	VITON/CHLOROBUTYL				FEP/SURLYN				CHLOROPEL				
CHRIS CODE	%WT INCR.	% ELONG.	3-HOUR PERMEATION GM PER SQ.M	COMMENT	%WT INCR.	% ELONG.	3-HOUR PERMEATION GM PER SQ.M	COMMENT	%WT INCR.	% ELONG.	3-HOUR PERMEATION GM PER SQ.M	COMMENT	GENERAL COMMENTS
NAC	9	0	N.D.	COLLIT	0	0	N.D.		8	-6	N.D.		
NIC	1	0	N.D.		8	22	N.D.		64	F	N.D.		
NSV	-5	0	N.D.		0	0	N.D.		2	0	N.D.		
NTB	2	0	N.D.		-4	0	N.D.		135	F	145.00		
PCB	3	0	N.D.		-1	0	N.D.		-6	0	N.D.		PCB IN HYDRAL. OIL
PRA	53		470.00	VDEG	1	0	N.D.		72	F	4060.00		
SAC	-5	0	N.D.		0	0	N.D.		0	0	N.D.		50% AQUEOUS
SFA	2	0	N.D.		-1	0	N.D.		16	0	N.D.	COLDAR	
TAP	-4	0	N.D.		-1	0	N.D.		1	0	N.D.		AQUEOUS
TCL	0	0	.03		-1	0	N.D.		145	F	3800.00		
TDI	-1	0	N.D.		-1	0	N.D.		56	F	N.D.		
TEC	1	0	N.D.		1	0	N.D.		206	F	420.00		
TEN	1	0	.80		0	0	N.D.		8	11	N.D.		PESTICIDE
THF	45	0	650.00	C,DELAM	-1	0	N.D.		122	F	2960.00		
TMC	0	0	N.D.		0	0	N.D.		9	11	N.D.		
VCM	6	0	N.D.		0	0	N.D.		5	0	N.D.		

N.D. INDICATES THAT NO PERMEATION WAS DETECTED AFTER THREE HOURS.
DETECTION LIMITS ARE LISTED IN TABLE 4.
SEE TABLE 1 FOR EXPLANATION OF ABBREVIATIONS IN COMMENT COLUMNS.

TABLE 12

BREAKTHROUGH TIMES AND SENSITIVITY
OF ANALYTICAL METHODS

Chemical, CHRIS Code	Breakthrough Time, minutes: Viton/ Chlorobutyl	FEP/ Surlyn	Chloropel	Analytical Method	Analytical Sensitivity $mg/m^2/3$ hrs
Acrylonitrile	70	nd	17	IR	1.3
Allyl Alcohol	nd	nd	120	IR	1.2
Allyl Chloride	3.5	nd	75	IR	2.1
n-Butyl Amine	21	nd	20	IR	1.0
Benzyl Chloride	nd	nd	47	IR	2.7
Barium Cyanide	nd	nd	nd	AA	1.0
Beryllium Nitrate	nd	nd	nd	AA	0.1
Benzene	nd	nd	26	IR	9.4
Benzene Phosphorous Thiodichloride	nd	nd	nd	IR	2.0
1,2-Butylene Oxide	10	nd	10	IR	4.0
Carbon Disulfide	nd	nd	8	IR	2.0
Carbolic Oil	nd	nd	nd	GC	0.7
Cyclohexyl Amine	57	nd	125	IR	2.2
Chloroform	165	nd	12	IR	-
Crotonaldehyde	105	nd	38	IR	1.7
4-Chloro-o-Toluidine	nd	nd	nd	SC	2.0
Cumene	nd	nd	78	IR	11.0
Dimethylacetamide	nd	nd	40	GC	2.0
Di-n-Butyl Amine	nd	nd	nd	GC	1.4
o-Dichlorobenzene	nd	nd	39	GC	1.0
Dichlorobutene	nd	nd	45	GC	3.2
Dodecydbenzene	nd	nd	nd	GC	0.01

TABLE 12 (Continued)

BREAKTHROUGH TIMES AND SENSITIVITY
OF ANALYTICAL METHODS

Chemical, CHRIS Code	Breakthrough Time, minutes			Analytical Method	Analytical Sensitivity $mg/m^2/3$ hrs
	Viton/ Chlorobutyl	FEP/ Surlyn	Chloropel		
Dichloroethyl Ether	nd	nd	80	IR	0.3
Dimethyldichlorosilane	nd	nd	nd	IC	10.0
Dichloropropane	nd	nd	36	IR	3.6
Ethyl Acrylate	26	nd	24	IR	0.5
2-Ethylhexyl Acrylate (inhibited)	nd	nd	nd	GC	0.04
Ethylene Dibromide	nd	nd	44	IR	1.3
Ethylene Dichloride	nd	nd	15	IR	1.0
Ethylene Cyanohydrin	nd	nd	nd	GC	0.7
Ethyl Methacrylate	30	nd	32	IR	1.3
Formaldehyde Sol'n	nd	nd	nd	IR	0.3
Hydrochloric Acid	nd	nd	nd	IC	10.0
Hydrogen Chloride	nd	nd	nd	IC	10.0
Hexamethyleneimine	nd	nd	155	GC	0.3
Isobutyronitrile	nd	nd	53	IR	1.0
Isooctaldehyde	nd	nd	nd	IR	2.0
Isoprpoyl Ether	nd	nd	nd	IR	0.7
Isovaleraldehyde	50	nd	35	IR	1.0
Mesityl Oxide	40	nd	25	IR	2.9
Nitric Acid	nd	nd	nd	IC	10.0
Nicotine	nd	nd	nd	SC	0.7
Naptha	nd	nd	nd	IR	-
Nitrobenzene	nd	nd	62	GC	2.0

TABLE 12 (Continued)

BREAKTHROUGH TIMES AND SENSITIVITY
OF ANALYTICAL METHODS

Chemical, CHRIS Code	Breakthrough Time, minutes Viton/ Chlorobutyl	FEP/ Surlyn	Chloropel	Analytical Method	Analytical Sensitivity $mg/m^2/3$ hrs
Polychlorinated Biphenyls	nd	nd	nd	SC	0.2
n-Propyl Amine	18	nd	9	IR	10.0
Sulfuric Acid (50%)	nd	nd	nd	IC	60.0
Sulfuric Acid	nd	nd	nd	IC	60.0
p-Toluene Sulfuric Acid	nd	nd	nd	IC	50.0
Trichloroethylene	25	nd	12	IR	0.4
Toluene-24-Disocyanate	nd	nd	nd	GC	8.0
Tetrachloroethane	nd	nd	64	IR	4.0
Triethylamine	9	nd	nd	IR	4.0
Tetrahydrofuran	8	nd	12	IR	1.0
Trimethylchlorosilane	nd	nd	nd	IC	10.0
Vinyl Chloride	nd	nd	nd	IR	2.0

TABLE 13

DISTRIBUTION OF BREAKTHROUGH TIMES FOR 56 CHRIS CHEMICALS AND THE THREE MATERIALS

	Number of Chemicals per Breakthrough Time (min) Interval				
Minutes	30	31-60	61-120	121-180	None[1]
Viton/Chlorobutyl	9	3	2	1	41
FEP/Surlyn	-	-	-	-	56
Chloropel	12	10	6	2	26

[1]No breakthrough was detected during the 3-hour permeation test.

three hours. The sensitivity of detection was 0.04 $mg/m^2/3$ hours.

Seam Testing

Seam Samples. ILC Dover provided Arthur D. Little, Inc. with sample seams using the selected materials. There were four material combinations of seams:

1) Chloropel to Chloropel - heat sealed
2) Chloropel to FEP/Surlyn - heat sealed
3) VITON/chlorobutyl to Viton/chlorobutyl - adhesive only
4) VITON/chlorobutyl to FEP/Surlyn - adhesive and stitching

Three types of Chloropel to Chloropel seams were tested in order to establish the strongest of the alternative designs:

1) Type A - fabricated from scrim-supported Chloropel
2) Type B - modified version of Type A.
3) Type C - seam of unsupported Chloropel.

These seams were specially constructed such that elongation (strength) tests could be performed following chemical exposure using the same apparatus as was used in immersion testing of the unseamed sheetstock materials. Sketches of the seamed test specimens are shown in Figure 4.

Procedure and Appartus. Seam strength tests were performed by measuring the seam's hydrostatic resistance with FEDERAL STANDARD METHOD 191,5122 and elongation following one-sided immersion. In FED STD 191,5212, the minimum burst pressure was determined by pressurizing water on one side of the seam until penetration was noted. Immersion testing of seams was conducted using the procedures described earlier (no weight change was measured; seams were subjected to elongation testing only). After the three-hour immersion period, the standard ASTM Die C specimen was cut from the center of the seam sample such that at one location the seam spanned the entire 0.25-inch width of the neck (see Figure 4). Thus, upon suspending a five-pound dead load from the specimen, the integrity of the seam could be determined.

Results. The minimum burst pressure recorded on all seams was 50 psi. The integrities of sample seams were also evaluated after three-hour exposures to twelve selected chemicals. The seam length was 0.25 inch and the seam was challenged with a five-pound dead load. The results are presented in Table 14. Three comments on these results are:

1) As would be expected, the Chloropel seams failed with those chemicals that caused relatively high changes in weight or elongation of the Chloropel itself.

2) For the VITON/chlorobutyl to VITON/chlorobutyl seam, it appeared that the VITON surface has been abraded in order to promote adhesion. Where the abraded area was not covered with adhesive, there was noticeable penetration of the chemical to the chlorobutyl rubber layer.

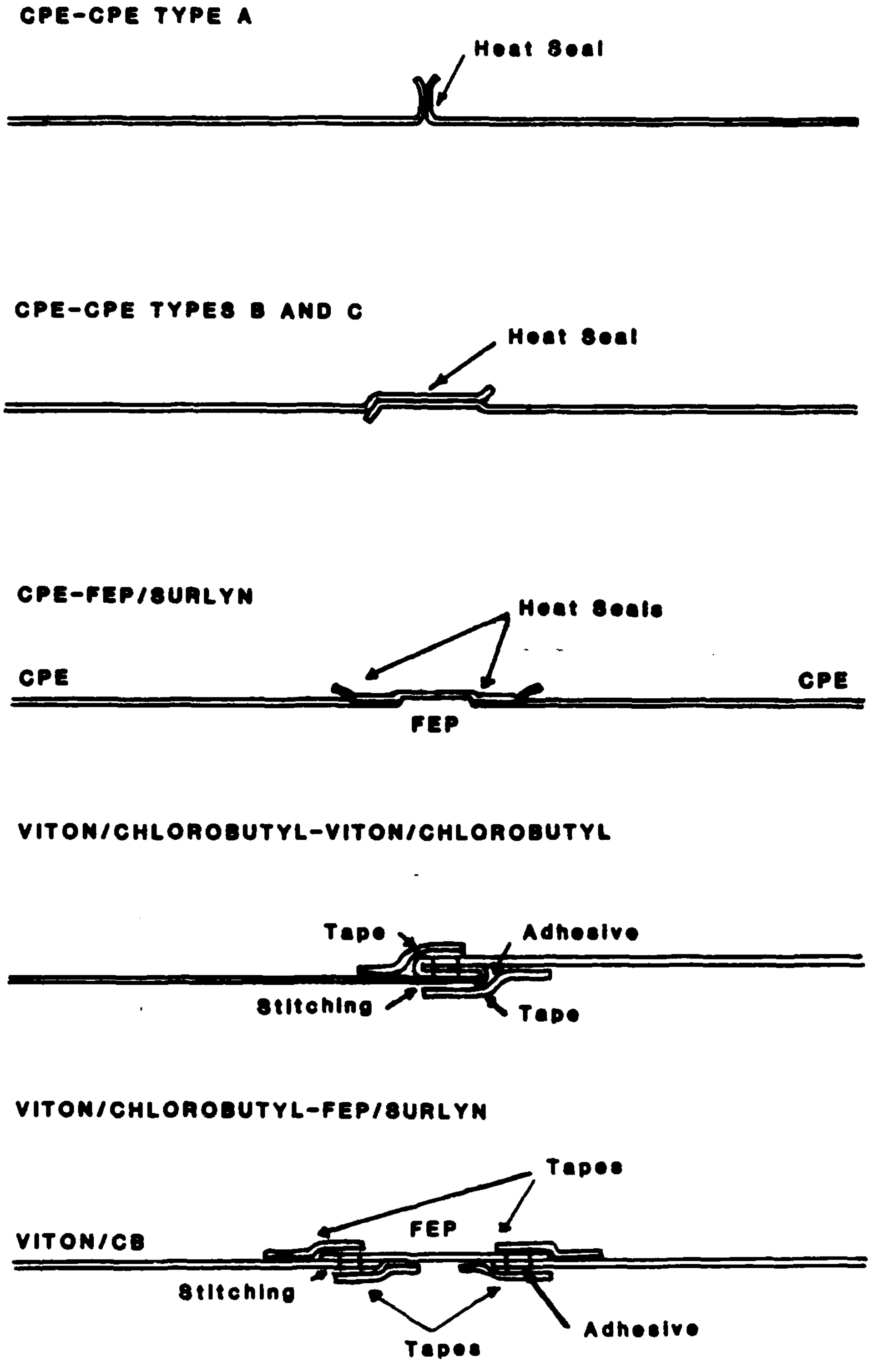


Figure 4. Material Seam Configurations

TABLE 14

SEAM TEST AFTER THREE-HOUR, SINGLE-SIDED IMMERSION IN CHEMICAL. VALUES INDICATE PERCENTAGE CHANGE IN ELONGATION[1]

Chemical	Chloropel-Chloropel Type A	Type B	Type C	Chloropel-FEP/Surlyn	Viton/Chlorobutyl-Viton/Chlorobutyl	Viton/Chlorobutyl-FEP/Surlyn
Allyl Alcohol	Fail	NT[2]	NT	0	0	0
Benzyl Chloride	Fail	NT	NT	Fail	0	Fail
Benzene	Fail	Fail	Fail	Fail	0	Fail
Chloroform	Fail	Fail	Fail	Fail	0	0
Di-n-Butyl Amine	Fail	Fail	70	Fail	0	Fail
Dodecylbenzene	Fail	0	0	0	0	0
2-Ethyl Hexyl Acetate (inhibited)	NT	200	NT	50	0	0
Ethylene Cyanohydrin	NT	0	NT	0	0	0
Formaldehyde Solution	Fail	0	0	0	0	0
Isooctaldehyde	NT	0	NT	0	0	0
Sulfuric Acid	0	NT	NT	0	0	0
Triethylamine	NT	0	NT	0	0	0

[1] Four-inch long, 0.25-inch wide neck, ASTM Die C specimen under five-pound dead load
[2] NT = Not Tested

3) The failures of the VITON/chlorobutyl to FEP/Surlyn seam appeared to be due to chemical attack of the adhesive used at the chlorobutyl to chlorobutyl interface.

Decontamination Testing

Procedure. After the three-hour permeation test, contaminated two-inch diameter pieces of test materials were subjected to a five-minute detergent (Alconox 0.75%) and water wash. The objective was to investigate washing as a means for decontaminating the materials. The extent of decontamination was to be judged by comparing the weight of the washed specimen with that of a similar area of unexposed material. This procedure is similar to that used by MSA Research Corp. in their evaluation of butyl rubber decontamination.

Results. Table 15 gives the results of the decontamination experiments. Two overall observations pertinent to the data are:

1) Significant quantities of chemical may remain in the fabrics after a detergent and water wash.

2) Detectable levels of chemical may remain in the fabrics which exhibit little or no weight variation from new fabrics.

It is apparent that, while the detergent and water wash may remove surface contamination, significant quantities of penetrating chemicals can remain in the fabrics after the wash.

Analysis and Significance of Material Testing Results

Correlation of Immersion and Permeation Test Results. Generally immersion testing is considered a screening technique for material-chemical compatibility, whereas permeation testing is a more detailed evaluation for chemical resistance. A side by side tabulation of immersion and permeation data are presented in Table 16. A comparison of the results show that, in most cases, significant indicators of degradation in immersion testing (greater than 10% weight change, elongation test failure, and visual signs of degradation) occur for material-chemical combinations where permeation is also observed. Of the 15 chemicals which permeated VITON/chlorobutyl laminate, there were 9 cases of significant weight change, none of elongation test failure, and 11 showing visual signs of deterioration in corresponding immersion testing. Three chemicals (Dimethylacetamide, Hexamethyleneimine, and Isobutyronitrile) demonstrated significant indicators for the immersion testing of the laminate, but no breakthrough during permeation testing. Conversely, Allyl chloride, Chloroform, Trichloroethylene, and Triethylamine, all permeated VITON/Chlorobutyl laminate within 3 hrs with no significant changes in weight, elongation, or visual appearance during immersion testing. Similarly, Allyl Alcohol and n-Butyl Amine had the same effects on the chloropel material. A number of chemicals (BPT, CTD, DBO, NIC, and TDI) caused severe degradation (in terms of weight change and elongation failure) of the chloropel, yet no permeation breakthrough was detected for these material-chemical combinations. Furthermore, less degradation was noted for

TABLE 15

RESULTS OF DECONTAMINATION TESTS

Chemical	Percent Change in Weight Following Exposure and Decontamination	Chemical Detected by odor or Appearance
Allyl Alcohol		
Viton/Chlorobutyl	-1	No
FEP/Surlyn	2	No
Chloropel	3	Yes
Benzyl Chloride		
Viton/Chlorobutyl	1	No
FEP/Surlyn	-3	No
Chloropel	Severely degraded beyond recovery	
Benzene Phosphorous Thiodichloride		
Viton/Chlorobutyl	-1	Yes
FEP/Surlyn	-1	No
Chloropel	78	Yes
Carbon Disulfide		
Viton/Chlorobutyl	0	Yes
FEP/Surlyn	2	No
Chloropel	22	Yes
Carbolic Oil		
Viton/Chlorobutyl	1	Yes
FEP/Surlyn	0	No
Chloropel	19	Yes
4-Chloro-o-toluidine		
Viton/Chlorobutyl	-	-
FEP/Surlyn	-	-
Chloropel	91	Yes
Cumene		
Viton/Chlorobutyl	-1	Yes
FEP/Surlyn	0	No
Chloropel	56	Yes
Dimethylacetamide		
Viton/Chlorobutyl	17	Yes
FEP/Surlyn	-1	No
Chloropel	65	Yes

TABLE 15 (continued)

RESULTS OF DECONTAMINATION TESTS

Chemical	Percent Change in Weight Following Exposure and Decontamination	Chemical Detected by odor or Appearance
Di-n-Butyl Amine		
Viton/Chlorobutyl	1	No
FEP/Surlyn	3	No
Chloropel	4	Yes
2-Ethylhexyl Acrylate (inhibited)		
Viton/Chlorobutyl	7	Yes
FEP/Surlyn	3	No
Chloropel	36	Yes
Ethylene Dichloride		
Viton/Chlorobutyl	4	No
FEP/Surlyn	3	No
Chloropel	Severely degraded beyong recovery	
Formaldehyde Solution		
Viton/Chlorobutyl	0	Yes
FEP/Surlyn	3	No
Chloropel	0	Yes
Hexamethyleneimine		
Viton/Chlorobutyl	25	Yes
FEP/Surlyn	-1	No
Chloropel	48	Yes
Isobutyronitrile		
Viton/Chlorobutyl	1	Yes
FEP/Surlyn	2	No
Chloropel	14	Yes
Isooctaldehyde		
Viton/Chlorobutyl	1	No
FEP/Surlyn	6	No
Chloropel	1	No
Isovaleraldehyde		
Viton/Chlorobutyl	1	Yes
FEP/Surlyn	3	Yes
Chloropel	28	Yes

TABLE 15 (continued)

RESULTS OF DECONTAMINATION TESTS

Chemical	Percent Change in Weight Following Exposure and Decontamination	Chemical Detected by odor or Appearance
Nicotine		
Viton/Chlorobutyl	4	Yes
FEP/Surlyn	-1	No
Chloropel	45	Yes
Nitrobenzene		
Viton/Chlorobutyl	5	Yes
FEP/Surlyn	1	No
Chloropel	Severely degraded beyond recovery	
Polychlorinated Biphenyl		
Viton/Chlorobutyl	0	Yes[1]
FEP/Surlyn	1	No
Chloropel	5	Yes[1]
p-Toluene Sulfonic Acid		
Viton/Chlorobutyl	1	No
FEP/Surlyn	3	No
Chloropel	-1	No
Trichloroethylene		
Viton/Chlorobutyl	5	Yes
FEP/Surlyn	3	No
Chloropel	Severely degraded beyond recovery	
Triethylamine		
Viton/Chlorobutyl	2	Yes
FEP/Surlyn	0	No
Chloropel	5	Yes

[1]High levels indicated by radiolabel in specimens

TABLE 16A

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR FLUORINATED ETHYLENE PROPYLENE/SURLYN LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
AAD	Acetaldehyde	0	-5			
ABM	Acetyl Bromide	0	0			
ACC	Acetyl Chloride	-2	0			
ACF	Allyl Chloroformate	-1	0			
ACL	Aluminum Chloride	-1	0			
ACN	Acrylonitrile	-1	0		ND	ND
ADN	Adiponitrile	-1	0			
ALA	Allyl Alcohol	0	0		ND	ND
ALC	Allyl Chloride	-1	0		ND	ND
APC	Antimony Pentachloride	1	0			
ARL	Acrolein	13	33	C		
ASC	Anisoyl Chloride	-3	-6			
ASU	Ammonium Bisulfate	0	0			
ATC	Allyl Trichlorosilane	NOT TESTED		INSUFCEM		
ATM	Antimony Trichloride	-2	0			
BAM	n-Butyl Amine	11	33		ND	ND
BBR	Benzyl Bromide	-3	0			
BCL	Benzyl Chloride	-3	0		ND	ND
BCY	Barium Cyanide	-1	0		ND	ND
BDE	Bisphenol A Diglycidyl Ether	-1	0			
BEN	Beryllium Nitrate	-1	0		ND	ND
BNZ	Benzene	0	0		ND	ND
BPT	Benzene Phosphorous Thiodichloride	-4	-5		ND	ND
BRX	Bromine	-2	0			
BRT	Boron Trichloride	0	0			
BTB	Boron Tribromide	-1	0			
BTO	1,2-Butylene Oxide	-2	0		ND	ND

TABLE 16A (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR FLUORINATED ETHYLENE PROPYLENE/SURLYN LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
CAC	Chloroacetyl Chloride	0	0			
CBB	Carbon Disulfide	-1	0		ND	ND
CBO	Carbolic Oil	-1	0		ND	ND
CBR	Cyanogen Bromide	0	0			
CCL	Cyanogen Chloride	0	0			
CDN	Chlordane	-1	0			
CES	Cupriethylenediamine Solution	1	0			
CHA	Cyclohexyl Amine	11	0		ND	ND
CLX	Chlorine	0	0			
CMA	Chromic Anhydride	-1	0			
CME	Chloromethyl Methyl Ether	-1	0			
CMH	Cumene Hydroperoxide	2	0			
COU	Coumaphos	0	0			
CPL	Chloropicrin, Liquid	-2	-5			
CRF	Chloroform	0	0		ND	ND
CRP	Chloroprene	-2	0			
CSA	Chlorosulfonic Acid	-1	0			
CTA	Crotonaldehyde	-1	0		ND	ND
CTD	4-Chloro-o-Toluidine	-2	0		ND	ND
CUM	Cumene	0	0		ND	ND
DAC	Dimethylacetamide	-6	0		ND	ND
DBA	Di-n-Butyl Amine	10	22		ND	ND
DBO	o-Dichlorobenzene	0	0		ND	ND
DCB	Dichlorobutene	-1	0		ND	ND
DCV	Dichlorovos	0	0			
DDB	Docdecylbenzene	1	0		ND	ND
DEE	Dichloroethyl Ether	-7	0		ND	ND

TABLE 16A (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS FOR FLUORINATED ETHYLENE PROPYLENE/SURLYN LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
DFA	Difluorophosphoric Acid (anhyd.)	-2	0			
DIH	Diisopropylbenzene Hydroperoxide	0	0			
DIS	Disulfton	0	0			
DIU	Diuron	-1	0			
DMD	Dimethyldichlorosilane	-1	0		ND	ND
DNA	Di-n-Propyl Amine	2	0			
DPD	Diphenyldichlorosilane	-1	0			
DPP	Dichloropropane	-2	0		ND	ND
DSL	Dimethyl Sulfide	-1	0			
DTN	Demeton	0	0			
DUR	Dursban	0	0			
EAC	Ethyl Acrylate	0	0		ND	ND
EAI	2-Ethylhexyl Acrylate, Inhibited	-1	0		ND	ND
EAM	Ethylamine	-4	-5			
ECF	Ethyl Chloroformate	0	0			
EDB	Ethylene Dibromide	1	0		ND	ND
EDC	Ethylene Dichloride	-2	0		ND	ND
EDR	Endrin	0	0			
ENB	Ethylidenenorborene	-1	0			
EOX	Ethylene Oxide	0	0			
EPD	Ethyl Phosphorothoic Dichloride	-2	0			
EPP	Ethyl Phosphorodichlorate	0	0			
ESF	Endosulfane	-2	0			
ETC	Ethylene Cyanohydrin	-5	0		ND	ND
ETM	Ethyl Methacrylate	1	0		ND	ND
ETO	Ethion	0	0			
ETS	Ethyltrichlorosilane	-1	0			

TABLE 16A (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR FLUORINATED ETHYLENE PROPYLENE/SURLYN LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
FCL	Ferric Chloride	-1	0			
FFB	Ferrous Fluoroborate	-1	0			
FMS	Formaldehyde Solution	-1	0		ND	ND
FSA	Fluorosulfonic Acid	1	0	PINHOLE		
FSL	Fluorosilicic Acid	-1	0			
GTA	Gluteraldehyde	0	0			
HBR	Hydrogen Bromide	-1	0			
HCL	Hydrochloric Acid	-4	0		ND	ND
HCN	Hydrogen Cyanide	0	0			
HDC	Hydrogen Chloride	-1	0		ND	ND
HFA	Hydrofluoric Acid	0	0			
HFX	Hydrogen Fluoride	4	0			
HMI	Hexamethyleneimine	-4	0		ND	ND
HMT	Hexamethylenetetramine	0	0			
IAI	Isodecyl Acrylate	3	0			
IAM	Isobutyl Amine	-1	0			
IBN	Isobutyronitrile	-3	0		ND	ND
IOC	Isooctaldehyde	-3	0		ND	ND
IPE	Isopropyl Ether	1	0	SC	ND	ND
IPM	Isopropyl Mercaptan	0	0			
IVA	Isovaleraldehyde	2	0		ND	ND
LRM	Lauryl Mercaptan	0	0			
MAM	Methyl Acrylate	8	28	SC		
MCH	Methyl Chloroformate	0	0			
MCS	Methyldichlorosilane	-3	-5			
MPY	1-Methyl Pyrolidone	-2	0			
MSO	Mesityl Oxide	-1	0		ND	ND

TABLE 16A (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR FLUORINATED ETHYLENE PROPYLENE/SURLYN LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
MTB	Methyl Bromide	1	0			
MTS	Methyltrichlorosilane	-3	0			
MVK	Methyl Vinyl Ketone	-1	0			
NAA	Nitrilotriacetic Acid and Salts	-2	0			
NAC	Nitric Acid	0	0		ND	ND
NCT	Naptha: Coal Tar	0	0			
NIC	Nicotine	8	22		ND	ND
NIE	o-Nitrotoluene	-1	0			
NOX	Nitrogen Tetroxide	1	0			
NSV	Naptha: Solvent	0	0		ND	ND
NTB	Nitrobenzene	-4	0		ND	ND
NTX	Nitric Oxide	-1	0			
OXA	Oxalic Acid	-1	0			
PAA	Peracetic Acid	-1	0			
PBR	Phosphorous Tribromide	-3	0			
PCB	Polychlorinated Biphenyl	-1	0		NT	ND
PCM	Perchloromethyl Mercaptan	-1	0			
PHG	Phosgene	4	0			
PHN	Phenol	-3	0			
PMN	n-Propyl Mercaptan	0	0			
PPO	Phosphorous Oxychloride	-1	0			
PPT	Phosphorous Trichloride	0	0			
PRA	n-Propylamine	1	0		ND	ND
PTL	Petrolatum	-1	0			
SAC	Sulfuric Acid, Spent	0	0		ND	ND
SCL	Sulfuryl Chloride	-2	0			
SDS	Sodium Sulfide	0	0			

TABLE 16A (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR FLUORINATED ETHYLENE PROPYLENE/SURLYN LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
SFA	Sulfuric Acid	-1	0		ND	ND
SFD	Sulfur Dioxide	2	0			
SFM	Sufur Monochloride	-2	0			
STC	Silicon Tetrachloride	-4	0			
STR	Strychnine	-1	-5			
TAP	p-Toluene Sulfonic Acid	-1	0		ND	ND
TCL	Trichloroethylene	-1	0		ND	ND
TDI	Toluene-2,4-Diisocyanate	-1	0		ND	ND
TEC	Tetrachloroethane	1	0		ND	ND
TEN	Triethylamine	0	0		ND	ND
TES	2,4,5-T (Esters)	-1	0			
THF	Tetrahydrofuran	-1	0		ND	ND
TMA	Trimethylamine	3	0	SC		
TMC	Trimethylchlorosilane	0	0		ND	ND
TPC	Thiophogene	-2	-5			
TTT	Titanium Tetrachloride	-2	0			
TXP	Toxaphene	3	0			
VCI	Vinylidenechloride, Inhibited	-2	0			
VCM	Vinyl Chloride	0	0		ND	ND
VFU	Vinyl Fluoride, Inhibited	0	0			
VTS	Vinyl Trichlorosilane	0	-5			
ZCL	Zinc Chloride	-4	0			
ZCT	Zirconium Tetrachloride	-1	0			
ZFB	Zinc Fluoroborate	-1	0			
ZPF	Zinc Potassium Fluoride	0	0			

TABLE 16B

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR VITON/CHLOROBUTYL LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
AAD	Acetaldehyde	10	0			
ABM	Acetyl Bromide	29	6			
ACC	Acetyl Chloride	20	0	BDEG		
ACF	Allyl Chloroformate	-2	0			
ACL	Aluminum Chloride	-5	0			
ACN	Acrylonitrile	9	0	C,DELAM	70	0.17
ADN	Adiponitrile	-2	0			
ALA	Allyl Alcohol	1	0		ND	ND
ALC	Allyl Chloride	1	0		3.5	50.00
APC	Antimony Pentachloride	1	0			
ARL	Acrolein	8	0	SC		
ASC	Anisoyl Chloride	1	0			
ASU	Ammonium Bisulfate	-3	0			
ATC	Allyl Trichlorosilane	1	0			
ATM	Antimony Trichloride	-5	0			
BAM	n-Butyl Amine	100	F	VDEG	21	1400.00
BBR	Benzyl Bromide	-4	0			
BCL	Benzyl Chloride	-2	0		ND	ND
BCY	Barium Cyanide	-2	0		ND	ND
BDE	Bisphenol A Diglycidyl Ether	1	0			
BEN	Beryllium Nitrate	-6	0		ND	ND
BNZ	Benzene	2	0		ND	ND
BPT	Benzene Phosphorous Thiodichloride	-4	0		ND	ND
BRX	Bromine	0	0			
BRT	Boron Trichloride	3	0			
BTB	Boron Tribromide	4	0	COLDAR		
BTO	1,2-Butylene Oxide	28	6	C	10	330.00

TABLE 16B (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS FOR VITON/CHLOROBUTYL LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
CAC	Chloroacetyl Chloride	4	0			
CBB	Carbon Disulfide	-5	0		ND	ND
CBO	Carbolic Oil	-1	0		ND	ND
CBR	Cyanogen Bromide	1	0			
CCL	Cyanogen Chloride	7	0			
CDN	Chlordane	-3	0			
CES	Cupriethylenediamine Solution	2	0			
CHA	Cyclohexyl Amine	27	0	HC	57	0.15
CLX	Chlorine	1	0	COLLIT		
CMA	Chromic Anhydride	-2	0			
CME	Chloromethyl Methyl Ether	22	0	SC		
CMH	Cumene Hydroperoxide	1	0			
COU	Coumaphos	3	0			
CPL	Chloropicrin, Liquid	6	0	SC		
CRF	Chloroform	4	0		165	0.01
CRP	Chloroprene	.5	0			
CSA	Chlorosulfonic Acid	43	0	C		
CTA	Crotonaldehyde	8	0	C	ND	ND
CTD	4-Chloro-o-Toluidine	-4	0		ND	ND
CUM	Cumene	-1	0		ND	ND
DAC	Dimethylacetamide	31	0	HC	ND	ND
DBA	Di-n-Butyl Amine	-6	0		ND	ND
DBO	o-Dichlorobenzene	-1	0		ND	ND
DCB	Dichlorobutene	-1	0		ND	ND
DCV	Dichlorovos	4	0			
DDB	Docdecylbenzene	2	0		ND	ND
DEE	Dichloroethyl Ether	2	0		ND	ND

TABLE 16B (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR VITON/CHLOROBUTYL LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
DFA	Difluorophosphoric Acid (anhyd.)	-1	0			
DIH	Diisopropylbenzene Hydroperoxide	2	0			
DIS	Disulfton	0	0			
DIU	Diuron	-1	0			
DMD	Dimethyldichlorosilane	0	0		ND	ND
DNA	Di-n-Propyl Amine	0	0			
DPD	Diphenyldichlorosilane	-3	0			
DPP	Dichloropropane	3	0		ND	ND
DSL	Dimethyl Sulfide	11	0	BUTWET		
DTN	Demeton	2	0			
DUR	Dursban	3	0			
EAC	Ethyl Acrylate	17	0	C	26	28.00
EAI	2-Ethylhexyl Acrylate, Inhibited	8	0	SC	ND	ND
EAM	Ethylamine	30	0	C,COLDAR		
ECF	Ethyl Chloroformate	22	0	C		
EDB	Ethylene Dibromide	0	0		ND	ND
EDC	Ethylene Dichloride	2	0		ND	ND
EDR	Endrin	-3	0			
ENB	Ethylidenenorborene	-5	0			
EOX	Ethylene Oxide	2	0			
EPD	Ethyl Phosphorothoic Dichloride	-2	0			
EPP	Ethyl Phosphorodichlorate	48	0	HC		
ESF	Endosulfane	1	0			
ETC	Ethylene Cyanohydrin	6	0		ND	ND
ETM	Ethyl Methacrylate	29	0	HC	30	63.00
ETO	Ethion	1	0			
ETS	Ethyltrichlorosilane	-3	0			

TABLE 16B (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR VITON/CHLOROBUTYL LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
FCL	Ferric Chloride	-4	0			
FFB	Ferrous Fluoroborate	0	0			
FMS	Formaldehyde Solution	0	0		ND	ND
FSA	Fluorosulfonic Acid	111	F			
FSL	Fluorosilicic Acid	-3	0			
GTA	Gluteraldehyde	-3	0			
HBR	Hydrogen Bromide	2	0	COLDAR		
HCL	Hydrochloric Acid	8	0	COLDAR	ND	ND
HCN	Hydrogen Cyanide	0	0			
HDC	Hydrogen Chloride	3	0	COLDAR	ND	ND
HFA	Hydrofluoric Acid	2	0	COLLIT		
HFX	Hydrogen Fluoride	4	0			
HMI	Hexamethyleneimine	18	0	C	ND	ND
HMT	Hexamethylenetetramine	0	0			
IAI	Isodecyl Acrylate	0	0			
IAM	Isobutyl Amine	106	F	VDEG		
IBN	Isobutyronitrile	16	0	HC	ND	ND
IOC	Isooctaldehyde	-1	0		ND	ND
IPE	Isopropyl Ether	8	0		ND	ND
IPM	Isopropyl Mercaptan	1	0			
IVA	Isovaleraldehyde	18	0	C	50	25.00
LRM	Lauryl Mercaptan	-3	0			
MAM	Methyl Acrylate	13	0	C		
MCH	Methyl Chloroformate	23	0	C		
MCS	Methyldichlorosilane	4	0			
MPY	1-Methyl Pyrolidone	31	11	HC		
MSO	Mesityl Oxide	29	6	HC	40	26.00

TABLE 16B (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR VITON/CHLOROBUTYL LAMINATE

CHRIS Code	Chemical Name	Immersion Data % Wgt. Change	% Elong. Change	Visual Obs.	Permeation Data Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
MTB	Methyl Bromide	8	0			
MTS	Methyltrichlorosilane	4	0			
MVK	Methyl Vinyl Ketone	19	6	C,BUTWET		
NAA	Nitrilotriacetic Acid and Salts	-2	0			
NAC	Nitric Acid	9	0	COLLIT	ND	ND
NCT	Naptha: Coal Tar	2	5			
NIC	Nicotine	1	0		ND	ND
NIE	o-Nitrotoluene	2	0			
NOX	Nitrogen Tetroxide	2	0	COLLIT		
NSV	Naptha: Solvent	-5	0		ND	ND
NTB	Nitrobenzene	2	0		ND	ND
NTX	Nitric Oxide	5	0	COLLIT		
OXA	Oxalic Acid	3	0			
PAA	Peracetic Acid	10	0	COLLIT		
PBR	Phosphorous Tribromide	1	0			
PCB	Polychlorinated Biphenyl	3	0		ND	ND
PCM	Perchloromethyl Mercaptan	0	0			
PHG	Phosgene	5	0			
PHN	Phenol	-3	0			
PMN	n-Propyl Mercaptan	-1	0			
PPO	Phosphorous Oxychloride	61	0			
PPT	Phosphorous Trichloride	0	0			
PRA	n-Propylamine	53	F	VDEG	18	470.00
PTL	Petrolatum	3	0			
SAC	Sulfuric Acid, Spent	-5	0		ND	ND
SCL	Sulfuryl Chloride	56	0	C,BDEG		
SDS	Sodium Sulfide	2	0			

TABLE 16B (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR VITON/CHLOROBUTYL LAMINATE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
SFA	Sulfuric Acid	2	0		ND	ND
SFD	Sulfur Dioxide	3	0			
SFM	Sufur Monochloride	-3	0			
STC	Silicon Tetrachloride	4	0			
STR	Strychnine	-1	0			
TAP	p-Toluene Sulfonic Acid	-4	0		ND	ND
TCL	Trichloroethylene	0	0		25	0.03
TDI	Toluene-2,4-Diisocyanate	-1	0		ND	ND
TEC	Tetrachloroethane	1	0		ND	ND
TEN	Triethylamine	1	0		9	0.80
TES	2,4,5-T (Esters)	1	6			
THF	Tetrahydrofuran	45	0	C,DELAM	8	650.0
TMA	Trimethylamine	-2	0			
TMC	Trimethylchlorosilane	0	0		ND	ND
TPC	Thiophogene	2	0			
TTT	Titanium Tetrachloride	-1	0			
TXP	Toxaphene	-1	0			
VCI	Vinylidenechloride, Inhibited	2	0			
VCM	Vinyl Chloride	6	0		ND	ND
VFU	Vinyl Fluoride, Inhibited	3	0			
VTS	Vinyl Trichlorosilane	-3	0			
ZCL	Zinc Chloride	-3	0			
ZCT	Zirconium Tetrachloride	-5	0			
ZFB	Zinc Fluoroborate	1	0			
ZPF	Zinc Potassium Fluoride	-1	0			

TABLE 16C

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR CHLORINATED POLYETHYLENE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
AAD	Acetaldehyde	24	11			
ABM	Acetyl Bromide	142	F			
ACC	Acetyl Chloride	72	F			
ACF	Allyl Chloroformate	7	0	COLDAR		
ACL	Aluminum Chloride	1	0			
ACN	Acrylonitrile	35	F		17	49.00
ADN	Adiponitrile	5	0			
ALA	Allyl Alcohol	2	11		120	0.15
ALC	Allyl Chloride	238	F	DELAM	75	ND
APC	Antimony Pentachloride	3	0			
ARL	Acrolein	35	F			
ASC	Anisoyl Chloride	61	0	C		
ASU	Ammonium Bisulfate	1	0			
ATC	Allyl Trichlorosilane	49	F			
ATM	Antimony Trichloride	1	0			
BAM	n-Butyl Amine	8	0		20	3470.00
BBR	Benzyl Bromide	126	F			
BCL	Benzyl Chloride	118	F		47	200.00
BCY	Barium Cyanide	2	0		ND	ND
BDE	Bisphenol A Diglycidyl Ether	3	0			
BEN	Beryllium Nitrate	2	0		ND	ND
BNZ	Benzene	60	F		26	800.00
BPT	Benzene Phosphorous Thiodichloride	64	0		ND	ND
BRX	Bromine	276	F			
BRT	Boron Trichloride	2	0	COLDAR		
BTB	Boron Tribromide	122	0			
BTO	1,2-Butylene Oxide	63	F		10	2400.00

TABLE 16C (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS FOR CHLORINATED POLYETHYLENE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m2)
CAC	Chloroacetyl Chloride	177	F			
CBB	Carbon Disulfide	33	F		8	2424.00
CBO	Carbolic Oil	13	0		ND	ND
CBR	Cyanogen Bromide	13	0			
CCL	Cyanogen Chloride	15	6	COLDAR		
CDN	Chlordane	8	0			
CES	Cupriethylenediamine Solution	0	0			
CHA	Cyclohexyl Amine	73	F		125	162.00
CLX	Chlorine	3	0			
CMA	Chromic Anhydride	1	0			
CME	Chloromethyl Methyl Ether	101	F			
CMH	Cumene Hydroperoxide	22	6			
COU	Coumaphos	42	F			
CPL	Chloropicrin, Liquid	173	F			
CRF	Chloroform	72	F		12	4000.00
CRP	Chloroprene	91	F			
CSA	Chlorosulfonic Acid	48	0	CPEDEG		
CTA	Crotonaldehyde	41	F		38	1743.00
CTD	4-Chloro-o-Toluidine	70	6		ND	ND
CUM	Cumene	57	F		78	89.00
DAC	Dimethylacetamide	95	F		40	563.00
DBA	Di-n-Butyl Amine	12	11		ND	ND
DBO	o-Dichlorobenzene	80	F		39	220.00
DCB	Dichlorobutene	161	F		45	609.00
DCV	Dichlorovos	76	F			
DDB	Docdecylbenzene	2	0		ND	ND
DEE	Dichloroethyl Ether	63	F		80	108.00

TABLE 16C (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS FOR CHLORINATED POLYETHYLENE

CHRIS Code	Chemical Name	Immersion Data: % Wgt. Change	Immersion Data: % Elong. Change	Immersion Data: Visual Obs.	Permeation Data: Breakthrough Time (min)	Permeation Data: 3 HR Permeation Amount (gm/m^2)
DFA	Difluorophosphoric Acid (anhyd.)	11	0	COLDAR		
DIH	Diisopropylbenzene Hydroperoxide	12	0			
DIS	Disulfton	24	0			
DIU	Diuron	3	0			
DMD	Dimethyldichlorosilane	44	F		ND	ND
DNA	Di-n-Propyl Amine	24	F			
DPD	Diphenyldichlorosilane	22	0			
DPP	Dichloropropane	120	F		36	702.00
DSL	Dimethyl Sulfide	91	F			
DTN	Demeton	27	F			
DUR	Dursban	55	F			
EAC	Ethyl Acrylate	160	F		24	500.00
EAI	2-Ethylhexyl Acrylate, Inhibited	34	6		ND	ND
EAM	Ethylamine	11	6			
ECF	Ethyl Chloroformate	94	F			
EDB	Ethylene Dibromide	187	F		44	1051.00
EDC	Ethylene Dichloride	147	F		15	1250.00
EDR	Endrin	59	F			
ENB	Ethylidenenorborene	17	11			
EOX	Ethylene Oxide	13	11			
EPD	Ethyl Phosphorothoic Dichloride	115	F			
EPP	Ethyl Phosphorodichlorate	93	F			
ESF	Endosulfane	57	F			
ETC	Ethylene Cyanohydrin	2	0		ND	ND
ETM	Ethyl Methacrylate	87	F		32	360.00
ETO	Ethion	21	F			
ETS	Ethyltrichlorosilane	38	11			

TABLE 16C (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS FOR CHLORINATED POLYETHYLENE

CHRIS Code	Chemical Name	Immersion Data: % Wgt. Change	% Elong. Change	Visual Obs.	Permeation Data: Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
FCL	Ferric Chloride	2	6			
FFB	Ferrous Fluoroborate	1	0			
FMS	Formaldehyde Solution	0	0		ND	ND
FSA	Fluorosulfonic Acid	84	F			
FSL	Fluorosilicic Acid	1	0			
GTA	Gluteraldehyde	1	0			
HBR	Hydrogen Bromide	6	0	COLDAR		
HCL	Hydrochloric Acid	1	0		ND	ND
HCN	Hydrogen Cyanide	0	0			
HDC	Hydrogen Chloride	0	0	COLDAR	ND	ND
HFA	Hydrofluoric Acid	6	0			
HFX	Hydrogen Fluoride	2	11			
HMI	Hexamethyleneimine	60	F		155	6.00
HMT	Hexamethylenetetramine	0	0			
IAI	Isodecyl Acrylate	20	0			
IAM	Isobutyl Amine	54	F			
IBN	Isobutyronitrile	36	F		53	197.00
IOC	Isooctaldehyde	3	0		ND	ND
IPE	Isopropyl Ether	3	0		ND	ND
IPM	Isopropyl Mercaptan	78	F			
IVA	Isovaleraldehyde	101	F		35	616.00
LRM	Lauryl Mercaptan	10	0			
MAM	Methyl Acrylate	57	F			
MCH	Methyl Chloroformate	85	F			
MCS	Methyldichlorosilane	53	F			
MPY	1-Methyl Pyrolidone	100	F			
MSO	Mesityl Oxide	130	F		25	2800.00

TABLE 16C (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS
FOR CHLORINATED POLYETHYLENE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
MTB	Methyl Bromide	19	0			
MTS	Methyltrichlorosilane	54	0			
MVK	Methyl Vinyl Ketone	82	F			
NAA	Nitrilotriacetic Acid and Salts	1	0			
NAC	Nitric Acid	8	-6		ND	ND
NCT	Naptha: Coal Tar	81	F			
NIC	Nicotine	64	F		ND	ND
NIE	o-Nitrotoluene	114	F			
NOX	Nitrogen Tetroxide	10	0			
NSV	Naptha: Solvent	2	0		ND	ND
NTB	Nitrobenzene	135	F		62	145.00
NTX	Nitric Oxide	5	0			
OXA	Oxalic Acid	2	0			
PAA	Peracetic Acid	4	0			
PBR	Phosphorous Tribromide	107	F			
PCB	Polychlorinated Biphenyl	-6	0		ND	ND
PCM	Perchloromethyl Mercaptan	86	F			
PHG	Phosgene	6	0			
PHN	Phenol	5	0			
PMN	n-Propyl Mercaptan	57	F			
PPO	Phosphorous Oxychloride	232	F			
PPT	Phosphorous Trichloride	128	0			
PRA	n-Propylamine	72	F		9	4060.00
PTL	Petrolatum	-2	0			
SAC	Sulfuric Acid, Spent	0	0		ND	ND
SCL	Sulfuryl Chloride	168	F			
SDS	Sodium Sulfide	1	0			

TABLE 16C (continued)

SIDE-BY-SIDE COMPARISON OF IMMERSION AND PERMEATION TESTING RESULTS FOR CHLORINATED POLYETHYLENE

		Immersion Data			Permeation Data	
CHRIS Code	Chemical Name	% Wgt. Change	% Elong. Change	Visual Obs.	Breakthrough Time (min)	3 HR Permeation Amount (gm/m^2)
SFA	Sulfuric Acid	16	0	COLDAR	ND	ND
SFD	Sulfur Dioxide	4	0			
SFM	Sufur Monochloride	182	F			
STC	Silicon Tetrachloride	9	0			
STR	Strychnine	3	0			
TAP	p-Toluene Sulfonic Acid	1	0		ND	ND
TCL	Trichloroethylene	145	F		12	3800.00
TDI	Toluene-2,4-Diisocyanate	56	F		ND	ND
TEC	Tetrachloroethane	206	F		64	420.00
TEN	Triethylamine	8	11		ND	ND
TES	2,4,5-T (Esters)	3	0	C		
THF	Tetrahydrofuran	122	F		12	2960.00
TMA	Trimethylamine	-1	0			
TMC	Trimethylchlorosilane	9	11		ND	ND
TPC	Thiophogene	126	F			
TTT	Titanium Tetrachloride	14	0	STIFFEN		
TXP	Toxaphene	6	0			
VCI	Vinylidenechloride, Inhibited	90	F			
VCM	Vinyl Chloride	5	0		ND	ND
VFU	Vinyl Fluoride, Inhibited	2	0			
VTS	Vinyl Trichlorosilane	56	11			
ZCL	Zinc Chloride	3	0			
ZCT	Zirconium Tetrachloride	2	0			
ZFB	Zinc Fluoroborate	0	0			
ZPF	Zinc Potassium Fluoride	0	0			

five other chemicals (CBO, DBA, DMD, EAI, and SFA) where again permeation was not detected for the majority of chloropel-chemical combinations. Significant indicators of degradation in immersion testing did not always correspond to detection of breakthrough in permeation testing. Based on these results, it appears that both immersion and permeation testing are needed to assess material chemical compatibility. Consequently, compatibility recommendations cannot be based on immersion testing alone.

Development of Compatibility Recommendation Criteria. Recommedation criteria were established to determine whether subject suit materials were compatible for use against the chemicals evaluated in this study. Recommendations for suit materials are limited to "pass" (compatible), "fail" (not compatible), or "unknown". The basis for these recommendations is as follows:

Pass - material compatible with chemical; no indications of degradation in immersion testing and no detection of breakthrough in permeation testing.

Fail - material not compatible with chemical; any indication of degradation in immersion testing or the detection of breakthrough in permeation testing.

Unknown - material compatibility uncertain; insufficient data for a recommendation (i.e. permeation testing not conducted).

Criteria leading to a "fail" recommendation are essentially consistent with the judgement of a significant indication used in the results. These include:

A - Chemical Permeation breakthrough within 3 hours

B - A material weight change greater than 10% following immersion testing

C - Failure of the material in the elongation (strength) test; sample breaks when subjected to 5 lb (20 lb/in) load

D - Elongation greater than 25% following immersion testing

E - Any visual sign of material deterioration involving polymer degradation, moderate to severe material curling, stiffening and the delamination. Material discoloration (lightening or darkening) and slight curling are not judged as deteriorations.

Material-Chemical Compatibility Recommendations. "Pass," "fail," and "unknown" recommendations are made for each material and chemcial combination testing in Table 17. Table 19 summarized these recommendations for each material while Table 20 breaks down the reasons for failure by material. A large number of "unknown" determinations exist since the majority of chemicals were not involved in permeation testing. A material-chemical combination could not be recommended "pass" unless permeation data was present to show no breakthrough for the three hour test period. On the other hand, a material-chemical combination could be judged "fail" on the basis of immersion test data in the absence of permeation testing. This approach was adopted by

TABLE 17

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
AAD	ACETALDEHYDE	Unk		Unk		Fail	B
ABM	ACETYL BROMIDE	Fail	B	Unk		Fail	B,C
ACC	ACETYL CHLORIDE	Fail	B,E	Unk		Fail	B,C
ACF	ALLYL CHLOROFORMATE	Unk		Unk		Unk	
ACL	ALUMINUM CHLORIDE	Unk		Unk		Unk	
ACN	ACRYLONITRILE *	Fail	A,E	Pass		Fail	
ADN	ADIPONITRILE	Unk		Unk		Unk	
ALA	ALLYL ALCOHOL *	Pass		Pass		Fail	A
ALC	ALLYL CHLORIDE *	Fail	A	Pass		Fail	A,B,C,E
APC	ANTIMONY PENTACHLORIDE	Unk		Unk		Unk	
ARL	ACROLEIN	Unk		Fail	B,D,E	Fail	B,C
ASC	ANISOYL CHLORIDE	Unk		Unk		Fail	B,E
ASU	AMMONIUM BISULFATE	Unk		Unk		Unk	
ATC	ALLYL TRICHLOROSILANE	Unk		NR		Fail	B,C
ATM	ANTIMONY TRICHLORIDE	Unk		Unk		Unk	
BAM	n-BUTYL AMINE *	Fail	A,B,C,E	Fail	B,C	Fail	A
BBR	BENZYL BROMIDE	Unk		Unk		Fail	
BCL	BENZYL CHLORIDE *	Pass		Pass		Fail	A,B,C
BCY	BARIUM CYANIDE *	Pass		Pass		Pass	
BDE	BISPHENOL A DIGLYCIDYL ETHER	Unk		Unk		Unk	
BEN	BERYLLIUM NITRATE *	Pass		Pass		Pass	
BNZ	BENZENE *	Pass		Pass		Fail	A,B,C
BPT	BENZENE PHOSPHORUS THIODICHLORIDE *	Pass		Pass		Fail	A
BRM	BROMINE	Unk		Unk		Fail	B,C
BRT	BORON TRICHLORIDE	Unk		Unk		Unk	
BTB	BORON TRIBROMIDE	Unk		Unk		Fail	B
BTO	1,2-BUTYLENE OXIDE *	Fail	A,B,E	Pass		Fail	A,B,C
CAC	CHLOROACETYL	Unk		Unk		Unk	

TABLE 17 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
CBB	CARBON DISULFIDE *	Pass		Pass		Fail	B
CBO	CARBOLIC OIL *	Pass		Pass		Fail	B
CBR	CYANOGEN BROMIDE	Unk		Unk		Fail	B
CCL	CYANOGEN CHLORIDE	Unk		Unk		Fail	B
CDN	CHLORDANE	Unk		Unk		Unk	
CES	CUPRIETHYLENEDIAMINE SOLUTION	Unk		Unk		Unk	
CHA	CYCLOHEXYL AMINE *	Fail	A,B,E	Fail	B	Fail	A,B,C
CLX	CHLORINE	Unk		Unk		Unk	
CMA	CHROMIC ANHYDRIDE	Unk		Unk		Unk	
CME	CHLOROMETHYL METHYL ETHER	Fail	B	Unk		Fail	B,C
CMH	CUMENE HYDROPEROXIDE	Unk		Unk		Fail	B
COU	COUMAPHOS	Unk		Unk		Fail	B,C
CPL	CHLOROPICRIN, LIQUID	Unk		Unk		Fail	B,C
CRF	CHLOROFORM *	Fail	A	Pass		Fail	A,B,C
CRP	CHLOROPRENE	Unk		Unk		Fail	B,C
CSA	CHLOROSULFONIC ACID	Fail	B,E	Unk		Fail	B,E
CTA	CROTONALDEHYDE *	Fail	A,E	Pass		Fail	A,B,C
CTD	4-CHLORO-o-TOLUIDINE *	Pass		Pass		Fail	B
CUM	CUMENE *	Pass		Pass		Fail	A,B,C
DAC	DIMETHYLACETAMIDE *	Fail	B,E	Pass		Fail	A,B,C
DBA	DI-n-BUTYL AMINE *	Pass		Pass		Fail	B
DBO	o-DICHLOROBENZENE *	Pass		Pass		Fail	B,C
DCB	DICHLOROBUTENE *	Pass		Pass		Fail	A,B,C
DCV	DICHLOROVOS	Unk		Unk		Fail	B,C
DDB	DODECYLBENZENE *	Pass		Pass		Pass	
DEE	DICHLOROETHYL ETHER *	Pass		Pass		Fail	A,B,C
DFA	DIFLUOROPHOSPHORIC ACID, ANHYDROUS	Unk		Unk		Fail	B
DIH	DIISOPROPYLBENZENE HYDROPEROXIDE	Unk		Unk		Fail	B
DIS	DISULFTON	Unk		Unk		Fail	B
DIU	DIURON	Unk		Unk		Unk	

TABLE 17 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
DMD	DIMETHYLDICHLOROSILANE *	Pass		Pass		Fail	B,C
DNA	DI-n-PROPYLAMINE	Unk		Unk		Fail	B,C
DPD	DIPHENYLDICHLOROSILANE	Unk		Unk		Fail	B
DPP	DICHLOROPROPANE *	Unk		Unk		Fail	A,B,C
DSL	DIMETHYL SULFIDE	Fail	B,E	Unk		Fail	B,C
DTN	DEMETON	Unk		Unk		Fail	B,C
DUR	DURSBAN	Pass		Pass		Fail	B,C
EAC	ETHYL ACRYLATE *	Fail	A,B,E	Pass		Fail	A,B,C
EAI	2-ETHYLHEXYL ACRYLATE, INHIBITED *	Pass		Pass		Fail	B
EAM	ETHYLAMINE	Fail	B,E	Unk		Fail	B
ECF	ETHYL CHLOROFORMATE	Fail	B,E	Unk		Fail	B,C
EDB	ETHYLENE DIBROMIDE *	Pass		Pass		Fail	A,B,C
EDC	ETHYLENE DICHLORIDE *	Pass		Pass		Fail	A,B,C
EDR	ENDRIN	Unk		Unk		Fail	B,C
ENB	ETHYLIDENENORBORNENE	Unk		Unk		Fail	B
EOX	ETHYLENE OXIDE	Unk		Unk		Fail	B
EPD	ETHYL PHOSPHOROTHIOIC DICHLORIDE	Unk		Unk		Fail	B,C
EPP	ETHYL PHOSPHORODICHLORIDATE	Fail	B,E	Unk		Fail	B,C
ESF	ENDOSULFANE	Unk		Unk		Fail	B,C
ETC	ETHYLENE CYANOHYDRIN *	Pass		Pass		Pass	
ETM	ETHYL METHACRYLATE *	Fail	A,B,E	Pass		Fail	A,B,C
ETO	ETHION	Unk		Unk		Fail	B,C
ETS	ETHYLTRICHLOROSILANE	Unk		Unk		Fail	B
FCL	FERRIC CHLORIDE	Unk		Unk		Unk	
FFB	FERROUS FLUOROBORATE	Unk		Unk		Unk	
FMS	FORMALDEHYDE SOLUTION *	Pass		Pass		Pass	
FSA	FLUOSULFONIC ACID	Fail	B,C	Unk		Fail	B,C
FSL	FLUOSILICIC ACID	Unk		Unk		Unk	
GTA	GLUTERALDEHYDE	Unk		Unk		Unk	
HBR	HYDROGEN BROMIDE	Unk		Unk		Unk	

TABLE 17 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
HCL	HYDROCHLORIC ACID *	Pass		Pass		Pass	
HCN	HYDROGEN CYANIDE	Unk		Unk		Unk	
HDC	HYDROGEN CHLORIDE	Pass		Pass		Pass	
HFA	HYDROFLUORIC ACID	Unk		Unk		Unk	
HFX	HYDROGEN FLUORIDE	Fail	E	Unk		Fail	E
HMI	HEXAMETHYLENEIMINE *	Fail	B,E	Pass		Fail	A,B,C
HMT	HEXAMETHYLENETETRAMINE	Unk		Unk		Unk	
IAI	ISODECYL ACRYLATE	Unk		Unk		Fail	B
IAM	ISOBUTYLAMINE	Fail	B,C,E	Unk		Fail	B,C
IBN	ISOBUTYRONITRILE *	Fail	B,E	Pass		Fail	A,B,C
IOC	ISOOCTALDEHYDE *	Pass		Pass		Pass	
IPE	ISOPROPYL ETHER *	Pass		Pass		Pass	
IPM	ISOPROPYL MERCAPTAN	Unk		Unk		Fail	B,C
IVA	ISOVALERALDEHYDE *	Fail	A,B,E	Pass		Fail	A,B,C
LPM	LAURYL MERCAPTAN	Unk		Unk		Unk	
MAM	METHYL ACRYLATE	Fail	B,E	Fail	D	Fail	B,C
MCH	METHYL CHLOROFORMATE	Fail	B,E	unk		Fail	B,C
MCS	METHYLDICHLOROSILANE	Unk		Unk		Fail	B,C
MPY	1-METHYL Pyrolidone	Fail	B,E	Unk		Fail	B,C
MSO	MESITYL OXIDE *	Fail	A,B,E	Pass		Fail	A,B,C
MTB	METHYL BROMIDE	Unk		Unk		Fail	B
MTS	METHYLTRICHLOROSILANE	Unk		Unk		Fail	B
MVK	METHYL VINYL KETONE	Fail	B,E	Unk		Fail	B,C
NAA	NITRILOTRIACETIC ACID AND SALTS	Unk		Unk		Unk	
NAC	NITRIC ACID *	Pass		Pass		Pass	
NCT	NAPHTHA: COAL TAR	Unk		Unk		Fail	B,C
NIC	NICOTINE *	Pass		Pass		Fail	B,C
NIE	o-NITROTOLUENE	Unk		Unk		Fail	B,C
NOX	NITROGRN TETROXIDE	Unk		Unk		Unk	
NSV	NAPHTHA: SOLVENT *	Pass		Pass		Pass	

TABLE 17 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
NTB	NITROBENZENE *	Pass		Pass		Fail	A,B,C
NTX	NITRIC OXIDE *	Unk		Unk		Unk	
OXA	OXALIC ACID	Unk		Unk		Unk	
PAA	PERACETIC ACID	Unk		Unk		Unk	
PBR	PHOSPHOROUS TRIBROMIDE	Unk		Unk		Fail	B,C
PCB	POLYCHLORINATED BIPHENYL	Pass		Pass		Pass	
PCM	PERCHLOROMETHYL MERCAPTAN	Unk		Unk		Fail	B,C
PHG	PHOSGENE	Unk		Unk		Unk	
PHN	PHENOL	Unk		Unk		Unk	
PMN	n-PROPYL MERCAPTAN	Unk		Unk		Fail	B,C
PPO	PHOSPHOROUS OXYCHLORIDE	Fail	B	Unk		Fail	B,C
PPT	PHOSPHOROUS TRICHLORIDE	Unk		Unk		Fail	B,C
PRA	n-PROPYLAMINE	Fail	A,B,C,E	Pass		Fail	A,B,C
PTL	PETROLATUM	Unk		Unk		Unk	
SAC	SULFURIC ACID, SPENT (50%)	Pass		Pass		Pass	
SCL	SULFURYL CHLORIDE	Fail	B,E	Unk		Fail	B,C
SDS	SODIUM SULFIDE	Unk		Unk		Unk	
SFA	SULFURIC ACID	Pass		Pass		Fail	B
SFD	SULFUR DIOXIDE	Unk		Unk		Unk	
SFM	SULFUR MONOCHLORIDE	Unk		Unk		Fail	B,C
STC	SILICON TETRACHLORIDE	Unk		Unk		Unk	
STR	STRYCHNINE	Unk		Unk		Unk	
TAP	p-TOLUENE SULFONIC ACID	Pass		Pass		Pass	
TCL	TRICHLOROETHYLENE	Fail	A	pass		Fail	A,B,C
TDI	TOLUENE-2,4-DIISOCYANATE	Pass		Pass		Fail	B,C
TEC	TETRACHLOROETHANE	Pass		Pass		Fail	A,B,C
TEN	TRIETHYLAMINE	Fail	A	Pass		Pass	
TES	2,4,5-T (ESTERS)	Unk		Unk		Fail	E
THF	TETRAHYDROFURAN	Fail	A,B,C	Pass		Fail	A,B,C
TMA	TRIMETHYLAMINE	Unk		Unk		Unk	

TABLE 17 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
TMC	TRIMETHYLCHLOROSILANE	Pass		Pass		Pass	
TPG	THIOPHOSGENE	Unk		Unk		Fail	B,C
TTT	TITANIUM TETRACHLORIDE	Unk		Unk		Fail	B,E
TXP	TOXAPHENE	Unk		Unk		Unk	
VCI	VINYLIDENECHLORIDE, INHIBITED	Unk		Unk		Fail	B,C
VCM	VINYL CHLORIDE	Pass		Pass		Pass	
VFI	VINYL FLUORIDE, INHIBITED	Unk		Unk		Unk	
VIS	VINYLTRICHLOROSILANE	Unk		Unk		Fail	B
ZCL	ZINC CHLORIDE	Unk		Unk		Unk	
ZCT	ZIRCONIUM TETRACHLORIDE	Unk		Unk		Unk	
ZFB	ZINC FLUOROBORATE	Unk		Unk		Unk	
ZPF	ZINC POTASSIUM FLUORIDE	Unk		Unk		Unk	

the Coast Guard since immersion testing does give indications of material degradation that appear to be often associated with permeation breakthrough. Nonetheless, even in the case of apparent material degradation vis-a-vis immersion testing without permeation breakthrough, significant weight change, elongation failure, or visible deterioration suggest material breakdown which could decrease overall garment integrity.

The original premise for the three hour duration of both immersion and permeation testing was based on an intended maximum stay time in the suit of 2.5 hours. During the course of this development, this requirement was reduced to 1 hour. The impact of this change affects the basis of the recommendation criteria. Since new testing was not performed, i.e. one hour immersion testing, the failure criteria were adapted for a 1 hour application, with less stringent requirements relevant to immersion testing.

A* - Chemical permeation breakthrough in 1 hour

B* - A material weight change greater than 25%

C* - Failure of the material in the elongation (strength) test; sample breaks when subjected to 5 lb (20 lb/in) load

E* - Any usual sign of material deterioration involving polymer degradation, severe curling, and delamination

Recommendations based on the above modified criteria appear in Table 18. Tables 19 and 20 give summaries of the recommendations and types failure by material. The difference of these results as shown by comparing material summaries of Tables 19 and 20 indicate few changes in the number of material-chemical combination "pass" recommendations. There is a limited increase of "pass" recommendations for each material (4- VITON/Chlorobutyl; 3 - FEP/Surlyn; 4 - CPE). There are also fewer failures. The most significant reduction in "fail" recommendations, 20 is noted for the chloropel. This is primarily due to relaxing the percent weight change criterion. With the new criteria, FEP/Surlyn has either a "pass" or "unknown" recommendation with no failures.

<u>Significance of Compatibility Recommendations</u>. On the basis of the new criteria and excluding "unknown" recommendations, VITON/Chlorobutyl laminate is recommeded for 62% (43 out of 71) of the rated chemicals, FEP/Surlyn laminate for all rated chemicals, and Chloropel for only 22% (21 of 97) rated chemicals. The choice of FEP/Surlyn fully meets the requirement for a visor material compatible to the same chemicals as the garment material. Overlapping chemical compatibility is provided for 20 chemicals by the VITON/Chlorobutyl laminate and chloropel. That leaves only 1 chemical (Triethylamine) which is judged compatible with Chloropel but not VITON/Chlorobutyl. This combined with the general poor performance of Chloropel would seem to provide little basis for the use of this material in the Coast Guard's HCPE System.

The Coast Guard decided to make a closer examination of the chemicals for which the materials were recommended and to also take into account economic considerations in analyzing the suit material compatibility recommendations.

TABLE 18

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS
BASED ON MODIFIED CRITERIA

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
AAD	ACETALDEHYDE	Unk		Unk		Unk	
ABM	ACETYL BROMIDE	Fail	B	Unk		Fail	B,C
ACC	ACETYL CHLORIDE	Fail	E	Unk		Fail	B,C
ACF	ALLYL CHLOROFORMATE	Unk		Unk		Unk	
ACL	ALUMINUM CHLORIDE	Unk		Unk		Unk	
ACN	ACRYLONITRILE *	Fail	E	Pass		Fail	
ADN	ADIPONITRILE	Unk		Unk		Unk	
ALA	ALLYL ALCOHOL *	Pass		Pass		Pass	
ALC	ALLYL CHLORIDE *	Fail	A	Pass		Fail	A,B,C,E
APC	ANTIMONY PENTACHLORIDE	Unk		Unk		Unk	
ARL	ACROLEIN	Unk		Unk		Fail	B,C
ASC	ANISOYL CHLORIDE	Unk		Unk		Fail	B,E
ASU	AMMONIUM BISULFATE	Unk		Unk		Unk	
ATC	ALLYL TRICHLOROSILANE	Unk		NR		Fail	B,C
ATM	ANTIMONY TRICHLORIDE	Unk		Unk		Unk	
BAM	n-BUTYL AMINE *	Fail	A,B,C,E	Pass		Fail	A
BBR	BENZYL BROMIDE	Unk		Unk		Fail	
BCL	BENZYL CHLORIDE *	Pass		Pass		Fail	A,B,C
BCY	BARIUM CYANIDE *	Pass		Pass		Pass	
BDE	BISPHENOL A DIGLYCIDYL ETHER	Unk		Unk		Unk	
BEN	BERYLLIUM NITRATE *	Pass		Pass		Pass	
BNZ	BENZENE *	Pass		Pass		Fail	A,B,C
BPT	BENZENE PHOSPHORUS THIODICHLORIDE *	Pass		Pass		Fail	A
BRM	BROMINE	Unk		Unk		Fail	B,C
BRT	BORON TRICHLORIDE	Unk		Unk		Unk	
BTB	BORON TRIBROMIDE	Unk		Unk		Fail	B
BTO	1,2-BUTYLENE OXIDE *	Fail	A,B	Pass		Fail	A,B,C
CAC	CHLOROACETYL CHLORIDE	Unk		Unk		Unk	

TABLE 18 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS
BASED ON MODIFIED CRITERIA

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL RECOMM.	VITON CHLOROBUTYL BASIS	FEP/SURLYN RECOMM.	FEP/SURLYN BASIS	CHLOROPEL RECOMM.	CHLOROPEL BASIS
CBB	CARBON DISULFIDE *	Pass		Pass		Fail	B
CBO	CARBOLIC OIL *	Pass		Pass		Pass	
CBR	CYANOGEN BROMIDE	Unk		Unk		Unk	
CCL	CYANOGEN CHLORIDE	Unk		Unk		Unk	
CDN	CHLORDANE	Unk		Unk		Unk	
CES	CUPRIETHYLENEDIAMINE SOLUTION	Unk		Unk		Unk	
CHA	CYCLOHEXYL AMINE *	Fail	A,B,E	Pass		Fail	B,C
CLX	CHLORINE	Unk		Unk		Unk	
CMA	CHROMIC ANHYDRIDE	Unk		Unk		Unk	
CME	CHLOROMETHYL METHYL ETHER	Unk		Unk		Fail	B,C
CMH	CUMENE HYDROPEROXIDE	Unk		Unk		Unk	
COU	COUMAPHOS	Unk		Unk		Fail	B,C
CPL	CHLOROPICRIN, LIQUID	Unk		Unk		Fail	B,C
CRF	CHLOROFORM *	Pass		Pass		Fail	A,B,C
CRP	CHLOROPRENE	Unk		Unk		Fail	B,C
CSA	CHLOROSULFONIC ACID	Fail	B	Unk		Fail	B,E
CTA	CROTONALDEHYDE *	Pass		Pass		Fail	A,B,C
CTD	4-CHLORO-o-TOLUIDINE *	Pass		Pass		Fail	B
CUM	CUMENE *	Pass		Pass		Fail	B,C
DAC	DIMETHYLACETAMIDE *	Fail	B,E	Pass		Fail	A,B,C
DBA	DI-n-BUTYL AMINE *	Pass		Pass		Fail	
DBO	o-DICHLOROBENZENE *	Pass		Pass		Fail	B,C
DCB	DICHLOROBUTENE *	Pass		Pass		Fail	A,B,C
DCV	DICHLOROVOS	Unk		Unk		Fail	B,C
DDB	DODECYLBENZENE *	Pass		Pass		Pass	
DEE	DICHLOROETHYL ETHER *	Pass		Pass		Fail	B,C
DFA	DIFLUOROPHOSPHORIC ACID, ANHYDROUS	Unk		Unk		Unk	
DIH	DIISOPROPYLBENZENE HYDROPEROXIDE	Unk		Unk		Unk	
DIS	DISULFTON	Unk		Unk		Unk	
DIU	DIURON	Unk		Unk		Unk	

TABLE 18 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS
BASED ON MODIFIED CRITERIA

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
DMD	DIMETHYLDICHLOROSILANE *	Pass		Pass		Fail	B,C
DNA	DI-n-PROPYLAMINE	Unk		Unk		Fail	C
DPD	DIPHENYLDICHLOROSILANE	Unk		Unk		Unk	
DPP	DICHLOROPROPANE *	Pass		Pass		Fail	A,B,C
DSL	DIMETHYL SULFIDE	Fail	B,E	Unk		Fail	B,C
DTN	DEMETON	Unk		Unk		Fail	B,C
DUR	DURSBAN	Pass		Pass		Fail	B,C
EAC	ETHYL ACRYLATE *	Fail	A	Pass		Fail	A,B,C
EAI	2-ETHYLHEXYL ACRYLATE, INHIBITED *	Pass		Pass		Fail	B
EAM	ETHYLAMINE	Unk		Unk		Fail	B
ECF	ETHYL CHLOROFORMATE	Unk	B,E	Unk		Fail	B,C
EDB	ETHYLENE DIBROMIDE *	Pass		Pass		Fail	A,B,C
EDC	ETHYLENE DICHLORIDE *	Pass		Pass		Fail	A,B,C
EDR	ENDRIN	Unk		Unk		Fail	B,C
ENB	ETHYLIDENENORBORNENE	Unk		Unk		Unk	B
EOX	ETHYLENE OXIDE	Unk		Unk		Unk	B
EPD	ETHYL PHOSPHOROTHIOIC DICHLORIDE	Unk		Unk		Fail	B,C
EPP	ETHYL PHOSPHORODICHLORIDATE	Fail	B,E	Unk		Fail	B,C
ESF	ENDOSULFANE	Unk		Unk		Fail	B,C
ETC	ETHYLENE CYANOHYDRIN *	Pass		Pass		Pass	
ETM	ETHYL METHACRYLATE *	Fail	A,B,E	Pass		Fail	A,B,C
ETO	ETHION	Unk		Unk		Fail	C
ETS	ETHYLTRICHLOROSILANE	unk		Unk		Fail	B
FCL	FERRIC CHLORIDE	Unk		Unk		Unk	
FFB	FERROUS FLUOROBORATE	Unk		Unk		Unk	
FMS	FORMALDEHYDE SOLUTION *	Pass		Pass		Pass	
FSA	FLUOSULFONIC ACID	Fail	B,C	Unk		Fail	B,C
FSL	FLUOSILICIC ACID	Unk		Unk		Unk	
GTA	GLUTERALDEHYDE	Unk		Unk		Unk	
HBR	HYDROGEN BROMIDE	Unk		Unk		Unk	

TABLE 18 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS
BASED ON MODIFIED CRITERIA

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
HCL	HYDROCHLORIC ACID *	Pass		Pass		Pass	
HCN	HYDROGEN CYANIDE	Unk		Unk		Unk	
HDC	HYDROGEN CHLORIDE	Pass		Pass		Pass	
HFA	HYDROFLUORIC ACID	Unk		Unk		Unk	
HFX	HYDROGEN FLUORIDE	Fail	E	Unk		Fail	E
HMI	HEXAMETHYLENEIMINE *	Pass		Pass		Fail	B,C
HMT	HEXAMETHYLENETETRAMINE	Unk		Unk		Unk	
IAI	ISODECYL ACRYLATE	Unk		Unk		Unk	
IAM	ISOBUTYLAMINE	Fail	B,C,E	Unk		Fail	B,C
IBN	ISOBUTYRONITRILE *	Fail	E	Pass		Fail	A,B,C
IOC	ISOOCTALDEHYDE *	Pass		Pass		Pass	
IPE	ISOPROPYL ETHER *	Pass		Pass		Pass	
IPM	ISOPROPYL MERCAPTAN	Unk		Unk		Fail	B,C
IVA	ISOVALERALDEHYDE *	Fail	A,B,E	Pass		Fail	A,B,C
LPM	LAURYL MERCAPTAN	Unk		Unk		Unk	
MAM	METHYL ACRYLATE	Unk		Unk		Fail	B,C
MCH	METHYL CHLOROFORMATE	Unk		Unk		Fail	B,C
MCS	METHYLDICHLOROSILANE	Unk		Unk		Fail	B,C
MPY	1-METHYL Pyrolidone	Fail	B,E	Unk		Fail	B,C
MSO	MESITYL OXIDE *	Fail	A,E	Pass		Fail	A,B,C
MTB	METHYL BROMIDE	Unk		Unk		Unk	
MTS	METHYLTRICHLOROSILANE	Unk		Unk		Fail	B
MVK	METHYL VINYL KETONE	Fail	E	Unk		Fail	B,C
NAA	NITRILOTRIACETIC ACID AND SALTS	Unk		Unk		Unk	
NAC	NITRIC ACID *	Pass		Pass		Pass	
NCT	NAPHTHA: COAL TAR	Unk		Unk		Fail	B,C
NIC	NICOTINE *	Pass		Pass		Fail	B,C
NIE	o-NITROTOLUENE	Unk		Unk		Fail	B,C
NOX	NITROGRN TETROXIDE	Unk		Unk		Unk	
NSV	NAPHTHA: SOLVENT *	Pass		Pass		Pass	

TABLE 18 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS
BASED ON MODIFIED CRITERIA

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
NTB	NITROBENZENE *	Pass		Pass		Fail	B,C
NTX	NITRIC OXIDE *	Unk		Unk		Unk	
OXA	OXALIC ACID	Unk		Unk		Unk	
PAA	PERACETIC ACID	Unk		Unk		Unk	
PBR	PHOSPHOROUS TRIBROMIDE	Unk		Unk		Fail	B,C
PCB	POLYCHLORINATED BIPHENYL	Pass		Pass		Pass	
PCM	PERCHLOROMETHYL MERCAPTAN	Unk		Unk		Fail	B,C
PHG	PHOSGENE	Unk		Unk		Unk	
PHN	PHENOL	Unk		Unk		Unk	
PMN	n-PROPYL MERCAPTAN	Unk		Unk		Fail	B,C
PPO	PHOSPHOROUS OXYCHLORIDE	Fail	B	Unk		Fail	B,C
PPT	PHOSPHOROUS TRICHLORIDE	Unk		Unk		Fail	B,C
PRA	n-PROPYLAMINE	Fail	A,B,C,E	Pass		Fail	A,B,C
PTL	PETROLATUM	Unk		Unk		Unk	
SAC	SULFURIC ACID, SPENT (50%)	Pass		Pass		Pass	
SCL	SULFURYL CHLORIDE	Fail	B,E	Unk		Fail	B,C
SDS	SODIUM SULFIDE	Unk		Unk		Unk	
SFA	SULFURIC ACID	Pass		Pass		Pass	
SFD	SULFUR DIOXIDE	Unk		Unk		Unk	
SFM	SULFUR MONOCHLORIDE	Unk		Unk		Fail	B,C
STC	SILICON TETRACHLORIDE	Unk		Unk		Unk	
STR	STRYCHNINE	Unk		Unk		Unk	
TAP	p-TOLUENE SULFONIC ACID	Pass		Pass		Pass	
TCL	TRICHLOROETHYLENE	Fail	A	pass		Fail	A,B,C
TDI	TOLUENE-2,4-DIISOCYANATE	Pass		Pass		Fail	B,C
TEC	TETRACHLOROETHANE	Pass		Pass		Fail	B,C
TEN	TRIETHYLAMINE	Fail	A	Pass		Pass	
TES	2,4,5-T (ESTERS)	Unk		Unk		Unk	
THF	TETRAHYDROFURAN	Fail	A,B,C	Pass		Fail	A,B,C
TMA	TRIMETHYLAMINE	Unk		Unk		Unk	

TABLE 18 (continued)

MATERIAL - CHEMICAL COMPATIBILITY RECOMMENDATIONS
BASED ON MODIFIED CRITERIA

CHRIS CODE	CHEMICAL COMPOUND	VITON CHLOROBUTYL		FEP/SURLYN		CHLOROPEL	
		RECOMM.	BASIS	RECOMM.	BASIS	RECOMM.	BASIS
TMC	TRIMETHYLCHLOROSILANE	Pass		Pass		Pass	
TPG	THIOPHOSGENE	Unk		Unk		Fail	B,C
TTT	TITANIUM TETRACHLORIDE	Unk		Unk		Unk	
TXP	TOXAPHENE	Unk		Unk		Unk	
VCI	VINYLIDENECHLORIDE, INHIBITED	Unk		Unk		Fail	B,C
VCM	VINYL CHLORIDE	Pass		Pass		Pass	
VFI	VINYL FLUORIDE, INHIBITED	Unk		Unk		Unk	
VIS	VINYLTRICHLOROSILANE	Unk		Unk		Fail	B
ZCL	ZINC CHLORIDE	Unk		Unk		Unk	
ZCT	ZIRCONIUM TETRACHLORIDE	Unk		Unk		Unk	
ZFB	ZINC FLUOROBORATE	Unk		Unk		Unk	
ZPF	ZINC POTASSIUM FLUORIDE	Unk		Unk		Unk	

TABLE 19

SUMMARY OF SUIT MATERIAL COMPATIBILITY RECOMMENDATIONS

Original Criteria[1]

	Pass	Fail	Unknown	Not Tested
VITON®/Chlorobutyl	39	35	86	0
FEP/Surlyn	55	4	100	1
Chloropel	17	95	42	0

Modified Criteria[2]

	Pass	Fail	Unknown	Not Tested
VITON®/Chlorobutyl	43	28	89	0
FEP/Surlyn	58	0	101	1
Chloropel	21	76	58	0

[1] Original criteria, see p 63.
[2] Modified criteria, see p 70.

TABLE 20

SUMMARY OF SUIT MATERIAL FAILURES

Original Criteria[1]

	A	B	C	D	E
VITON^R/Chlorobutyl	15	28	5	0	26
FEP/Surlyn	0	3	0	3	1
Chloropel	29	96	71	0	6

Modified Criteria[2]

	A	B	C	E
VITON^R/Chlorobutyl	12	15	4	17
FEP/Surlyn	0	0	0	0
Chloropel	23	77	71	3

1 Original criteria, see p 63.
2 Modified criteria, see p 70.

Appendix B provides a Coast Guard survey of spilled substances. Using the results of this investigation and those from MSA Study for butyl rubber, suit material recommendations were made for the majority of the chemicals listed in Appendix B. These recommendations appear in Table 21. When more than one material was compatible for a particular chemical, the estimated cost of the garment was considered and the least expensive suit chosen. For example, the cost of a VITON/Chlorobutyl garment is predicted to be 3 to 4 times greater than that of a Chloropel suit, based on material costs and differences in fabrication. Though VITON/Chlorobutyl and butyl rubber suits would be fabricated in similar ways, the cost of butyl rubber material is substantially less, making it a less costly suit.

An analysis of the compatibility recommendations together with spill frequency and suit cost considerations show how a three suit material system might be employed. The summary below shows the relative numbers of both chemicals and chemical spills (chemical spill frequency) that each suit material would protect against:

	Approx Cost(1)	Number of Chemicals	Pct.	Number of Spills	Pct.
Butyl Rubber	$1200	11	20	421	26
Chloropel	500	7	15	877	55
VITON/Chlorobutyl	1500	10	18	63	4
None Recommended		10	18	106	7
Insufficient Data		18	29	127	8

NOTE: 1. 1981 Cost Estimates

In spite of poor test results, suits made of Chloropel could be used the majority of time, whereas VITON/Chlorobutyl suits which have relatively broad chemical resistance would find limited employment. Nevertheless the three material HCPE system allows response personnel to be protected against many more CHRIS chemicals than if suits used were based on a single material. The difficulty in a multimaterial suit system is selection in the cases of unknown chemicals or chemical mixtures. If personnel entry is dictated by the On-scene Commander, these situations would require judicious selection of the appropriate protective suit. It is suspected that the best overall suit, that constructed from VITON/chlorobutyl laminate might be used in these cases. On the other hand, chloropel suits should not employed for unknown chemicals or chemical mixtures due to their poor overall performance against many of the CHRIS chemicals. Additional testing will continue to determine which other CHRIS chemicals are compatible to the selected suit materials as the development continues.

TABLE 21

OUTERGARMENT MATERIAL RECOMMENDATION
FOR SPILLED SUBSTANCES

COMPOUND	CHRIS CODE	ANNUAL NO. OF SPILLS	RECOMMENDED MATERIAL	ALTERNATE MATERIALS
Acetaldehyde	AAD	35	Insuff.	
Acetic Acid	AAC	90	Butyl	
Acetic Anhydride	ACA	10	Butyl	
Acrylonitrile	ACN	12	None	
Allyl Alcohol	ALA	NR	Viton	
Allyl Chloride	ALC	3	None	
Benzene	BNZ	9	Viton	
Benzyl Chloride	BCL	2	Viton	
Bromine	BRM	3	Insuff.	
Butyl Amine	BAM	2	None	
Carbon Disulfide	CBB	6	Viton	
Chlorine	CLX	20	Insuff.	
Chlorodane	CDN	2	Insuff.	
Chloroform	CRF	4	Viton	
Chloropicrin	CPL	7	Insuff.	
Chlorosulfonic Acid	CAS	6	None	
Cumene Hydroperoxide	CMH	4	Insuff.	
Cyanides (Sodium, Potassium, Sol'n)	---	5	Butyl	
Cyanogen Bromide	CBR	2	Insuff.	
Cyanogen Chloride	CCL	NR	Insuff.	
Cyclohexane	---	6	Butyl	
Dichlorobenzene	DCB	1	Viton	
1,2-Dichloropropane	DPP	NR	Viton	
Dichlorovos	DCV	NR	Insuff.	

TABLE 21 (continued)

OUTERGARMENT MATERIAL RECOMMENDATION
FOR SPILLED SUBSTANCES

COMPOUND	CHRIS CODE	ANNUAL NO. OF SPILLS	RECOMMENDED MATERIAL	ALTERNATE MATERIALS
Dimethyl Sulfate	DSL	4	Insuff.	
Ethyl Acrylate	EAC	38	None	
Ethylene Dichloride	EDC	2	Viton	
Ethylene Oxide	EOX	1	Insuff.	
Formaldehyde	FMS	18	CPE	Viton
Hexane	HEX	8	Insuff.	
Hydrazine	HDZ	7	Butyl	
Hydrogen Chloride Hydrochloric Acid	HDC HCL	305	CPE	Viton
Hydrogen Cyanide Hydrocyanic Acid	HEN	2	CPE	Viton
Hydrogen Fluoride Hydrofluoric Acid	HFX HFA	35	None	
Hydrogen Peroxide	HPO	35	Butyl	
Mercury	MCR	5	Butyl	
Methyl Bromide	MTB	2	None	
Naptha, Coal Tar	NCT	22	CPE	Viton
Nitric Acid	NAC	101	CPE	Viton
Nitrobenzene	NTB	8	Viton	
Nitrogen Tetroxide	NOX	NR	Insuff.	
o-Nitrotoluene	NIE	NR	Insuff.	
Parathion	PTO	10	Butyl	
Phenol	PHN	38	Insuff.	
Phosgene	PHG	NR	Insuff.	

TABLE 21 (continued)

OUTERGARMENT MATERIAL RECOMMENDATION
FOR SPILLED SUBSTANCES

COMPOUND	CHRIS CODE	ANNUAL NO. OF SPILLS	RECOMMENDED MATERIAL	ALTERNATE MATERIALS
Phosphorous Oxychloride	PPO	9	None	
Phosphorous Tribromide	PBR	1	Insuff.	
Potassium Hydroxide (sol'n or dry)	PTH	56	Butyl	
Silicon Tetrachloride	STC	2	Insuff.	
Sodium Hydroxide (sol'n or dry)	SHD	193	Butyl	
Sulfuric Acid	SFA	426	CPE	
Tetrahydrofuran	THF	13	None	
Titanium Tetrachloride	TTT	4	Insuff.	
Toluene Diuisocyanate	TDI	6	None	
Vinyl Chloride	VCM	3	CPE	Viton

CHAPTER 3

DESIGN OF THE HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

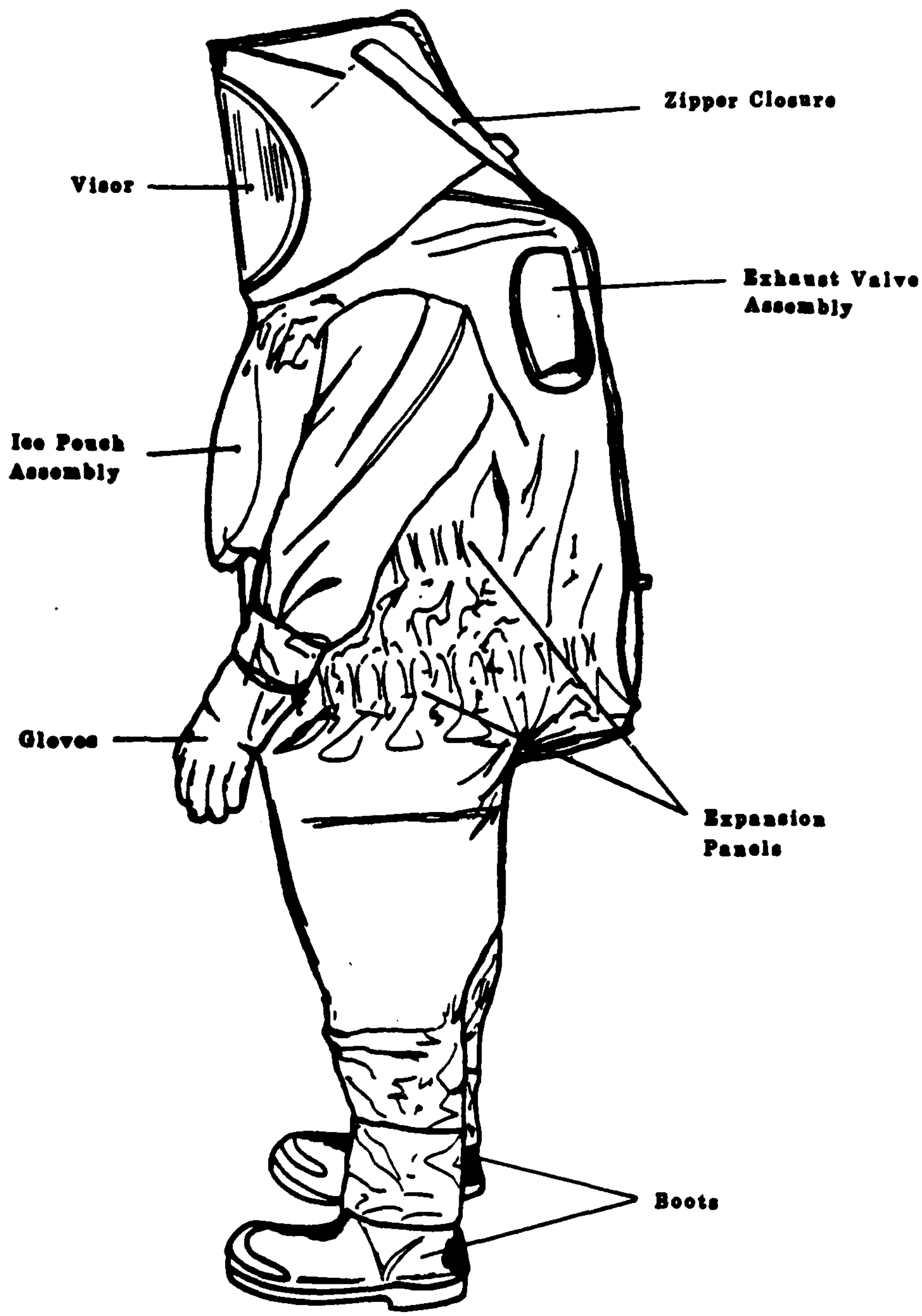
The objective of Task II was to develop a Hazardous Chemical Protective Ensemble (HCPE) which integrated a self-contained breathing apparatus, liquid cooling system, communications equipment, and totally-encapsulating outergarment into one ensemble design. Outergarment materials selected in Task I (VITON/chlorobutyl laminate, butyl rubber, and chlorinated polyethylene) were to provide as complete resistance to all chemicals identified in the CHRIS list as possible in a minimum of material-suit combinations. The design of the outergarment was to have the same operational characteristics and general configuration regardless of the material used. The entire ensemble was to provide Level A protection as defined by the U. S. Environmental Protection Agency for protection of personnel against both chemical vapors and liquid splashes.[4]

Outergarment

The outergarment design concept developed for the HCPE was a totally encapsulating garment configured to accept the Environmental Control Unit (ECU) which provided breathing air and cooling, and communications equipment within the envelope of the outergarment. This would ensure that the equipment was protected from a contaminated environment since the chemical effects on these items were unknown. ILC Dover used many of the characteristics in its commercial and other self-contained protective suit developments (i.e., the Dimilitarized Protective Ensemble and the Model 51 Chemturion) as models for the Coast Guard outergarment design.

Seams. The design configuration for the outergarment, sketched in Figure 5, was the same for all materials with the only difference being in the construction of the suit seams. The butyl and VITON/chlorobutyl laminate materials required that the seams be stitched and, in order to prevent leakage through the needle holes, the stitching was coated with an neoprene based adhesive and tape was applied over the seam (see Figure 4). A polyester thread was used in this seam construction; the seam tapes were simply one inch strips of same material as that for the outergarment. The CPE garment was fabricated using a radio-frequency sealing technique that yielded integral, leak-proof half inch lap seams (see Figure 4).

Visor. A integral visor was selected to prevent the possibility of chemical penetration in the head area of the outergarment. FEP/Surlyn laminate was used with all three garment materials. ILC Dover laminated the 1 mil FEP to the 20 mil Surlyn using heated press (250°C at 44,000 psi for six minutes). This material was flexible at its overall thickness and became a simple extension of the upper torso in a hood-like configuration. Seams of the visor material with the outergarment material required stitching for each material type since ILC Dover experienced problems with heat sealing CPE directly to the FEP/Surlyn and still maintaining structural strength. Visor-garment seams for the butyl and VITON/laminate suits employed tapes of



TOTAL ENCAPSULATING SUIT DESIGN

Figure 5

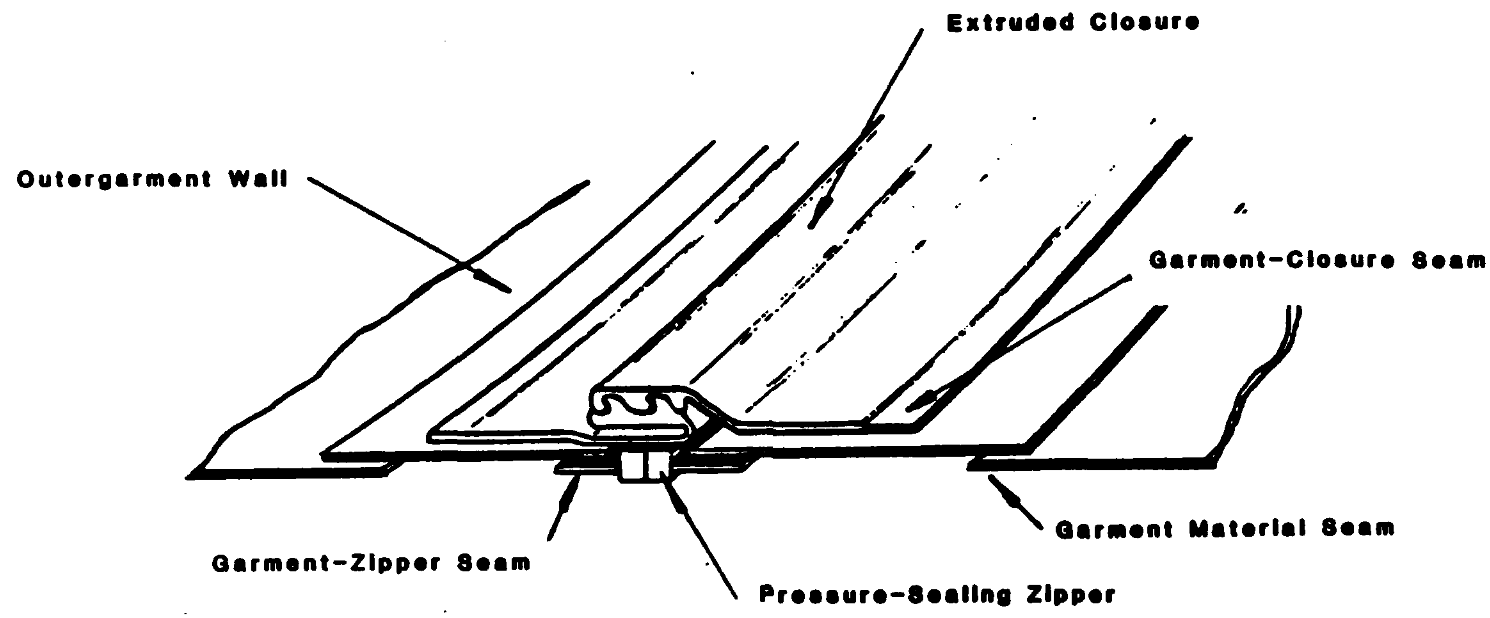
the same material bonded over the edge of the visor with a neoprene based adhesive. Tapes of CPE were heat sealed over the inner Surlyn part of the visor and bonded on the FEP side.

Sizing. The garments were to be sized to accomodate the 5th to 95th percentile range of sizes (using military data). ILC Dover recommended three sizes: small, medium, and large based on their experience in sizing its commercial encapsulating garments. However, the Coast Guard chose to use one size (large) for fabricating suit prototypes and was to later consider a three suit size system for production. The large size generally fit large-build persons up to a height of 6'6". Shorter users (less than 5'6") had difficulty in seeing out of the suit visor. The VITON/chlorobutyl and butyl rubber suits had a weight of 10.5 pounds (less the cooling system pouch) whereas the CPE suit weighed approximately 13 pounds.

Closure Assembly. Each outergarment had an extruded closure and restraint zipper to provide entry into the garment (Figure 6). The outer closure was a two-track interlocking seal that provided resistance to chemical penetration. The inner restraint zipper protected the outer closure from structural loads that might tend to pull the seal open. The outer closure on the CPE garment was extruded from the same material as the outergarment, while the closures on the butyl and VITON/chlorobutyl laminate garments were extruded from a chlorobutyl compound. The inner closure was a Talon OEB pressure sealing zipper having neoprene tape and brass chain, sliders, and pulls. The inner closure was stitched and bonded to the garment material with a neoprene based adhesive. ILC Dover believed that the relative thickness of the outer closure (approximately 0.080 inch) would provide chemical resistance as good as the VITON/chlorobutyl laminate. Yet, testing was never conducted to verify this belief. The closure assembly was installed in the rear of the garment for ease of entry, access to the ECU, protection of the closure (due to uncertain chemical resistance), and to avoid interference with the ensemble cooling system located on the front of the outergarment (described later).

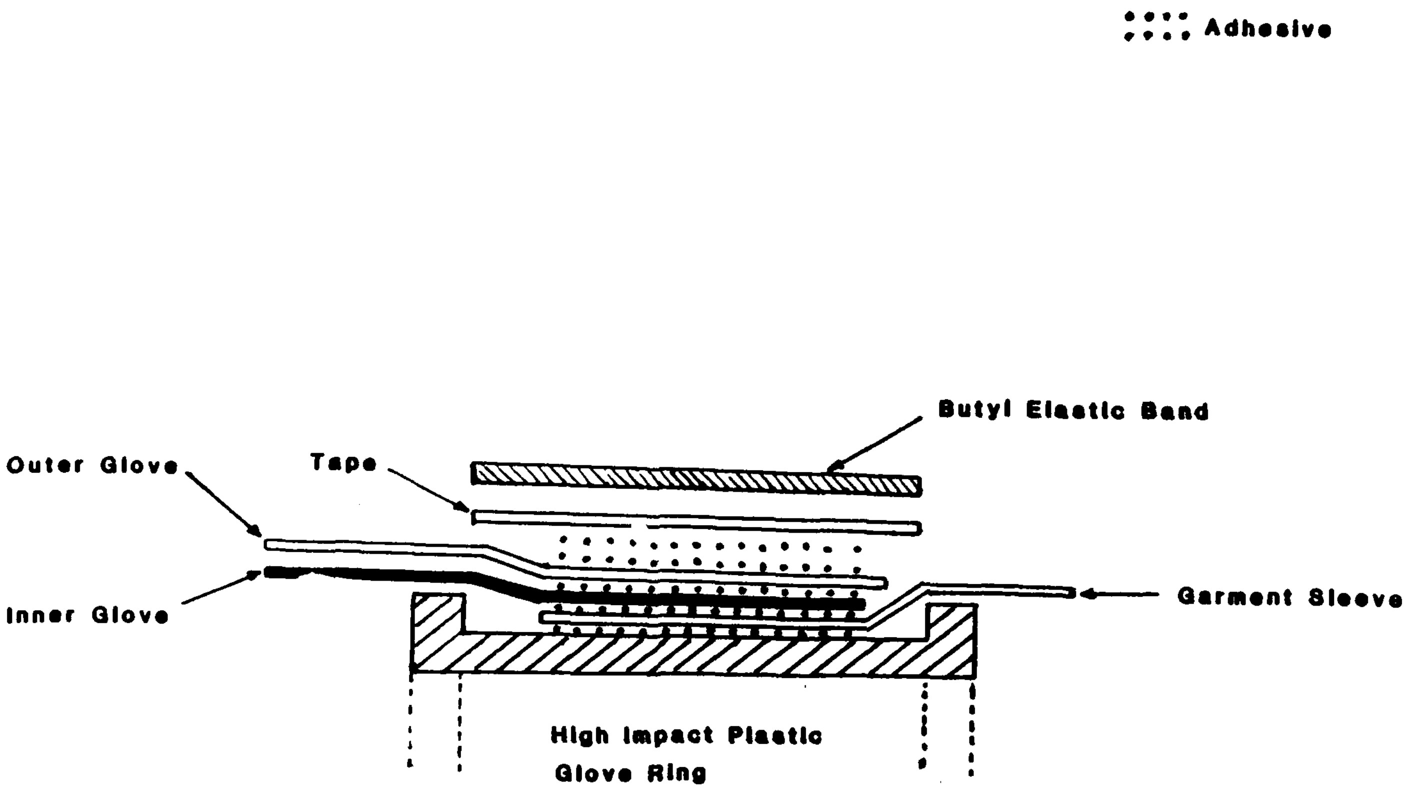
Hand and Foot Protection. Each outergarment had 0.012 VITON gloves integrally bonded to the sleeves at a cuff ring located at the wrist (Figure 7). The cuff ring was a 5 inch diameter one inch wide ring made out of high impact plastic. Use of the cuff ring allowed the ensemble user to withdraw his hands and make adjustments on his or her breathing apparatus inside the suit. Sock-like booties were fabricated from the base material attached to the overgarment. These gloves and boot-socks acted as liners and ensured that the garment remained totally encapsulating without the use of additional sealing surfaces at glove or boot disconnects. A 0.028 inch thick butyl rubber overglove was used over the liner glove to provide additional chemical protection as well as protection against abrasion and puncture. Similarly, the Coast Guard planned that overboots would be worn over the sock-like bootie. Flanges on the lower arms and legs were provided to roll down over the edges of the overgloves and boots. These flanges reduced the possibility of chemical impinging on the glove or boot edge and collecting between the boot/glove liners and the outer layers.

Suit Pressurization System. A key feature of the ensemble was its suit pressurization system, which was designed to provide positive pressure (i.e. greater than ambient) within the garment. The use of positive pressure



CLOSURE ASSEMBLY CONFIGURATION

Figure 6



GLOVE RING ASSEMBLY CONFIGURATION

Figure 7

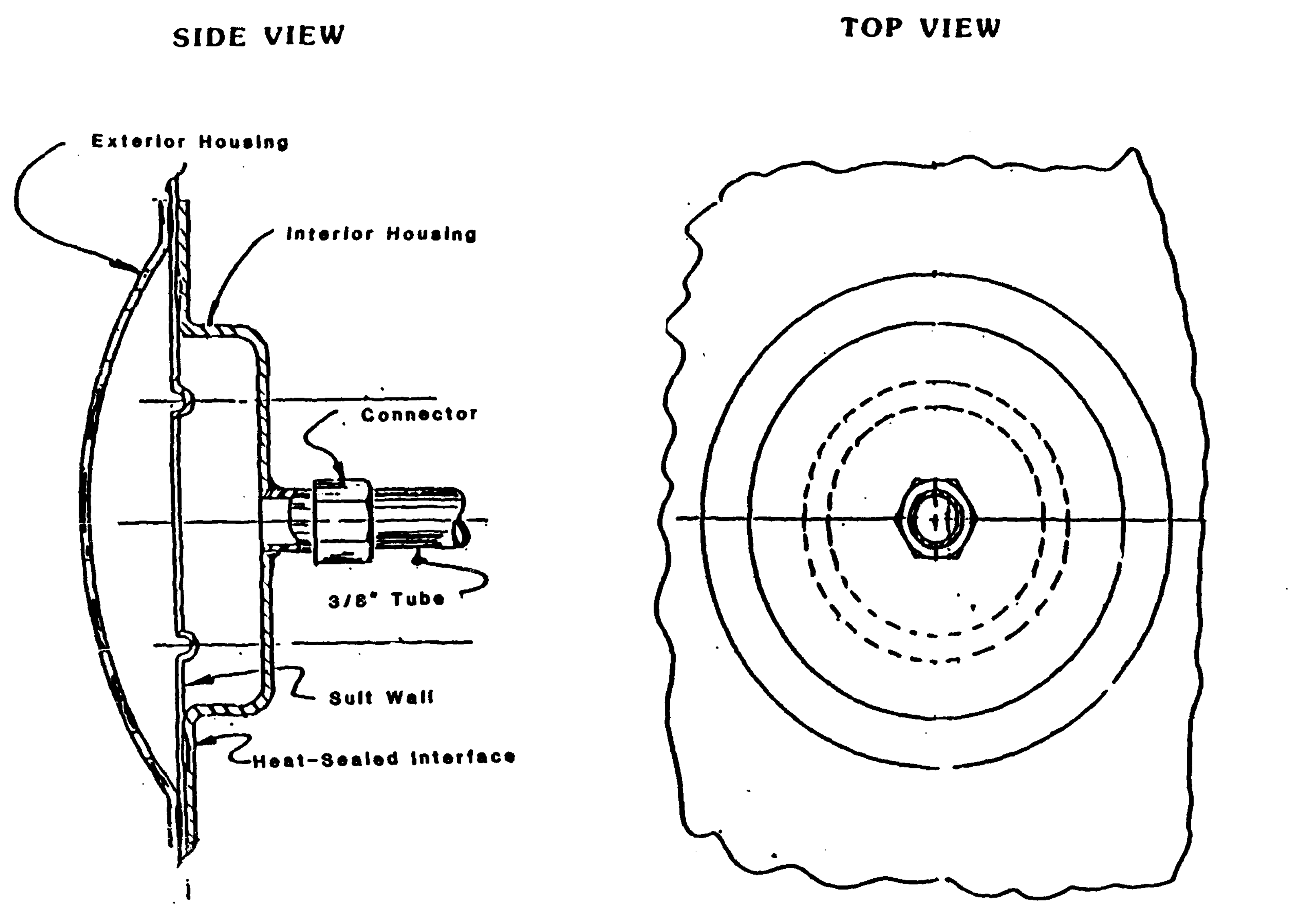
operation within the garment was to prevent contamination from entering the ensemble should a leak occur as caused by a puncture or tear in the outergarment. Internal suit pressurization was to be maintained by the ensemble breathing system, either by leakage around the facepiece during exhalation with a rebreather (closed-circuit) system, or by the direct .xhalation from an open-circuit self-contained breathing apparatus. To prevent excessive pressure within the garment, pressure relief valves were installed in the outergarment. Four Halkey Roberts one-way check valves set at a cracking pressure of 2.0 inches water guage were used. These valves were located on the left rear shoulder area of the outergarment and covered by an inverted pocket for protection against liquid chemical splashes.

Suit Volume Accumulators. To maintain a positive pressure within the ensemble at all times, it was necessary to incorporate a means of volume accumulation in the overgarment design. The purpose of volume accumulation was to maintain constant suit volume during a full range of body movements. For example, when the ensemble wearer went from a standing position into a crouch, excess air would be expelled through the relief valves as the suit volume was reduced. When the wearer stood up again, the volume accumulator would reduce the volume of the garment to compensate for the air that expelled during the crouch motion. The design configuration of the volume accumulators were simply 2.0 inch wide elastics sewn into a strip of garment material when it was in the fully stretched position. This assembly was then sealed or sewn to the outergarment wall in four places; directly under the arms, and in the hip area, on both sides of the garment (see Figure 5). The pre-stretched elastic relaxes and pleats the suit wall, which allowed it to expand or contract as required to maintain positive pressure within the ensemble.

Environmental Control Unit

The Environmental Control Unit (ECU) was initially specified for use in the Hazardous Chemical Protective Ensemble. The basis and feasibility for the ECU was developed by MSA Research Corporation for the Coast Guard in Contract DOT-CG-73210-A.[5] The ECU was envisioned as a multipurpose system which would provide an extended period of breathing air (2-1/2 hours), aid in maintaining suit pressurization, and contain some elements of the ensemble cooling system. Essentially, the ECU was a closed-circuit (non-exhausting) positive pressure rebreather. Oxygen depleted in the user's exhaust air would be made up with oxygen from a cylinder with carbon dioxide removed in scrubber cannister. The ECU also contained a small pressurized air bottle to provide make-up air should the pressure in the outergarment drop below 0.4 inches water guage pressure. A controller in the ECU was designed to respond to the difference in internal suit and ambient pressures as sensed by a diaphragm built into the suit wall (Figure 8). Lastly, the ECU also housed the circulating pump for ensemble cooling system and a water sleeve for cooling the inhalation air coming out of the CO_2 scrubber.

The Environmental Control Unit was being developed for ILC Dover by U. S. Divers, Survivair Division under contract DAAK11-80-C-0059. When the outergarment was being designed, this 2-1/2 hour system still needed further development. At that time, there were concerns that the ECU would not be the most desirable ensemble component in terms of availability and cost. The



OUTERGARMENT PRESSURE SENSING DIAPHRAGM FOR ECU

Figure 8

AD-A174 885 EARLY DEVELOPMENT OF A HAZARDOUS CHEMICAL PROTECTIVE 2/2
ENSEMBLE(U) COAST GUARD WASHINGTON DC OFFICE OF
RESEARCH AND DEVELOPMENT J O STULL OCT 86 USCG-D-24-86
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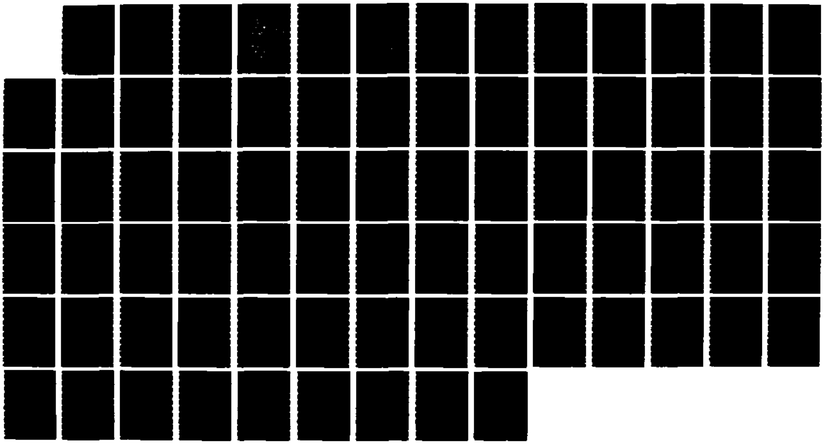
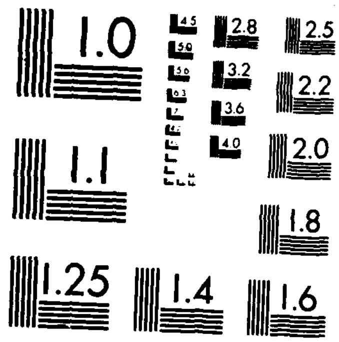




CROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

Coast Guard also decided that a one hour ensemble use period was more realistic than 2-1/2 hours, primarily on the basis of field experiences and user heat stress. The Coast Guard therefore requested that the ensemble outergarment accomodate a variety of commercial self-contained breathing (SCBA) systems. This would greatly increase the flexibility of the ensemble and afford end-users the option of using whichever breathing system he or she was most comfortable and confident with.

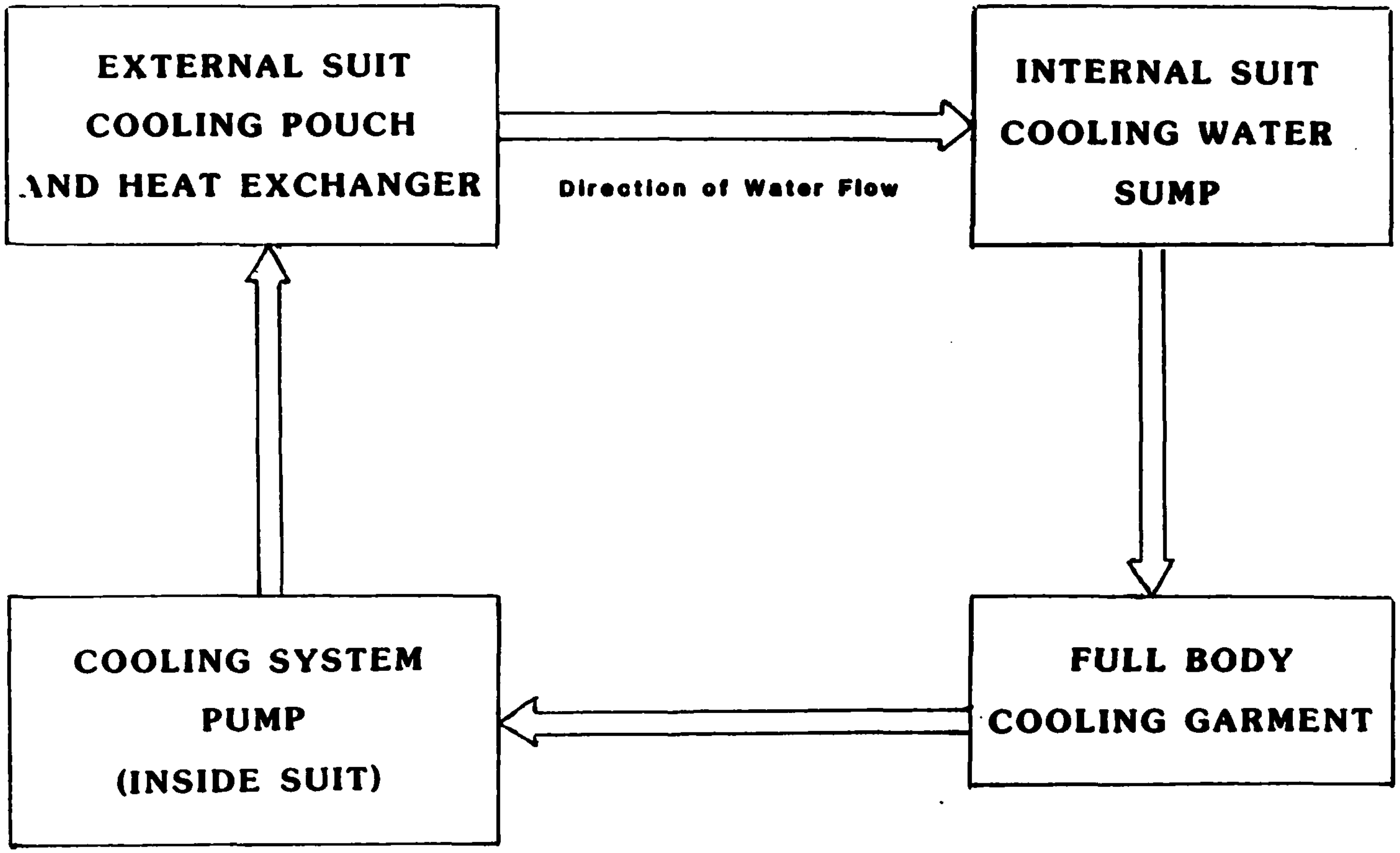
The HCPE outergarment was designed to meet the space requirements of the U. S. Divers prototype 2-1/2 hour breathing system. Other commercially available rebreather systems contemplated for use in the outergarment, such as the Siebe Gorman (Aerolox), Draeger, and Biomarine systems, appeared compatible with the outergarment design. Yet, their use in the ensemble would not provide sufficient air to maintain the positive pressure, lacking the make-up air supply of the ECU. Additionally, a cooling sleeve for the inhalation air hose would be necessary to remove the heat build-up in the air as the result of respiration and the carbon dioxide scrubbing process. At the same time in the development, one-hour (4500 psi) open-circuit SCBA's were being offered by some manufacturers. These breathing systems were lighter, simpler in design, and had greater user acceptance than rebreathers having similar capabilities. The dimensions of the open-circuit SCBA's also seemed compatible with the overgarment design. ILC Dover recommended that the outergarment exhaust valves be sized accordingly for the different types of breathing systems if both were to be used in the field.

Cooling System

The cooling system developed for the HCPE was designed based on a closed-loop water-recirculating cooling concept. This type of cooling system was recommended by MSA Research Corporation in their study for the feasibility of a self-contained Environmental Control Unit.[5] The system consisted of three parts: a full body cooling garment, a heat exchanger/ice-water slurry reservoir, and a centrifugal pump. The system worked by picking up body heat through the liquid cooled full body garment and transferring this excess body heat via a heat exchanger to the ice-water/water reservoir that could be replenished when depleted. This refillable system design enabled the ice-water reservoir to be sized to a convenient weight, while still cooling the man for the length of the mission. Figure 9 shows the overall configuration for the HCPE cooling system.

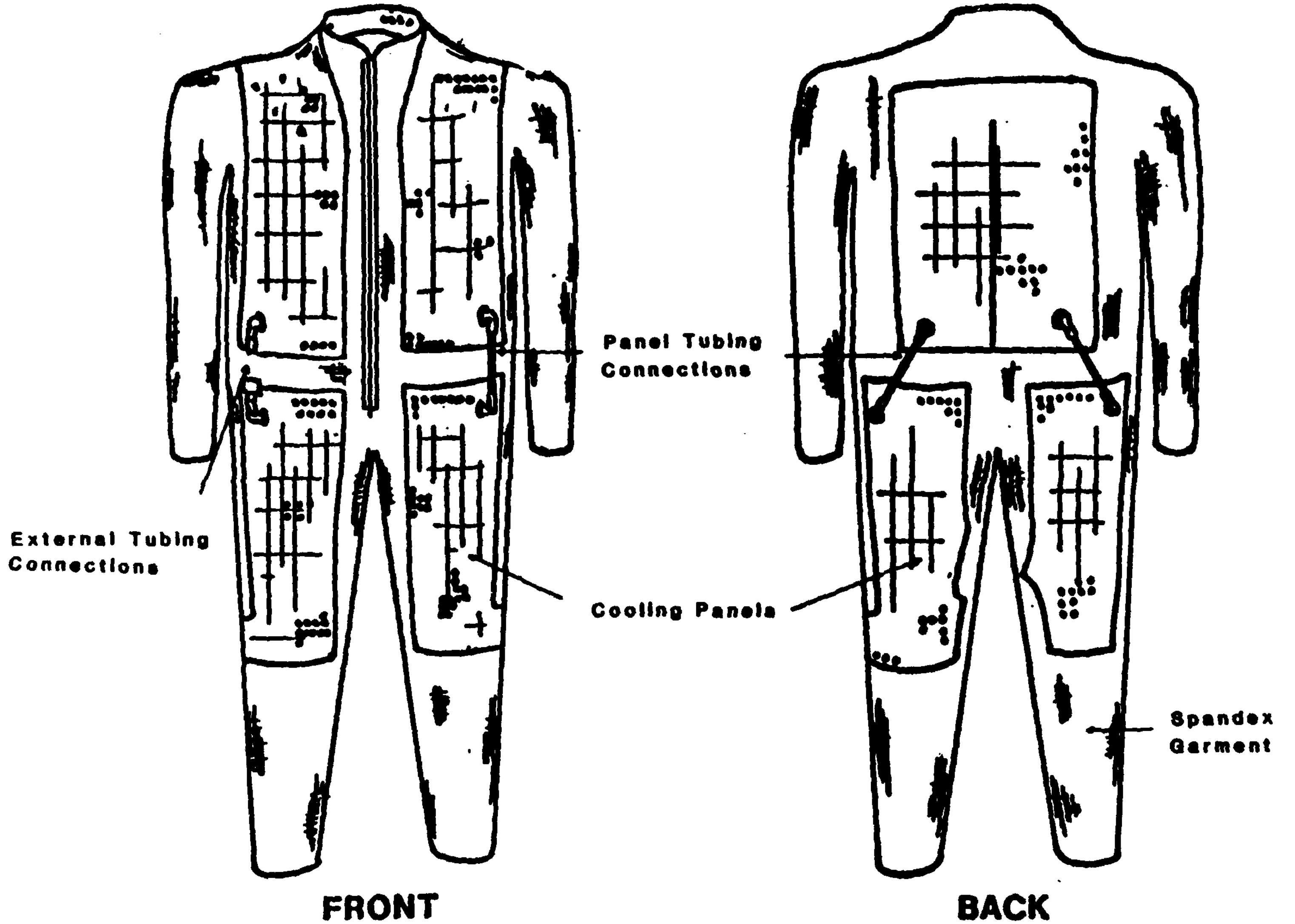
Full-Body Cooling Garment. The full-body cooling garment was developed by ILC Dover under contracts DAAK11-79-C-0060 and DAAK11-80-C-0020. It consisted of cooling panels located at the neck, front and back torso, and front and back upper legs, through which the cooling media (water) flowed. These panels were constructed of polyurethane coated nylon and were located in areas where large amounts of blood flow occurred in order to maximize the cooling effciency of the garment. TYGON tubing was used to connect the individual panels which were integrated into a spandex comfort liner that covered the body to the wrists and ankles as shown in Figure 10.

Heat Exchanger and Cooling Pouch Assembly. The cooling garment interfaced with a heat exchanger installed on the upper front of the outergarment. The



COOLING SYSTEM CONFIGURATION

Figure 9



FULL BODY COOLING GARMENT DESIGN

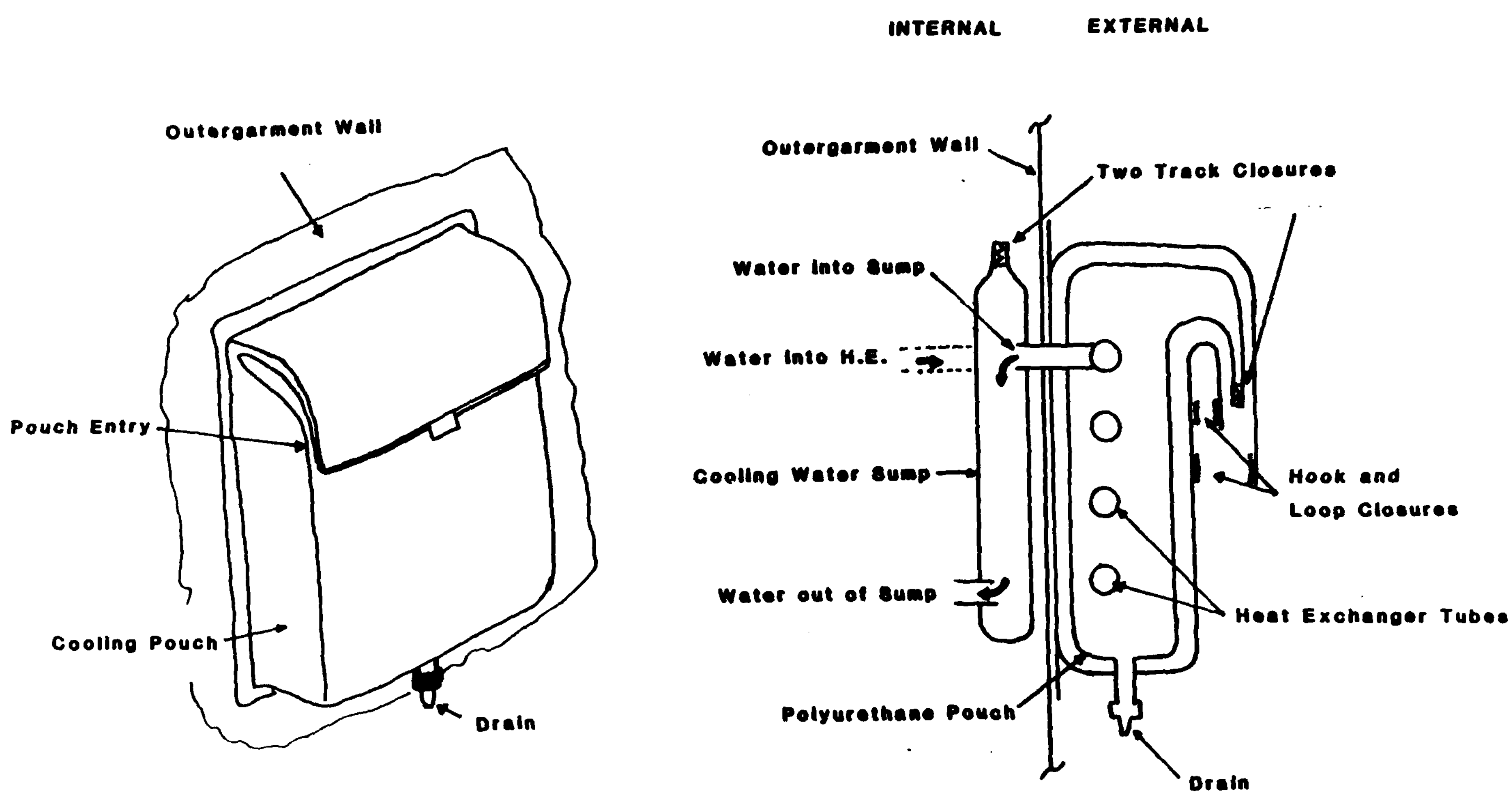
Figure 10

purpose of the heat exchanger was to remove heat from the water circulating through the cooling garment after it had passed through the cooling panels. The design configuration of the heat exchanger was approximately five feet of copper tubing bent into a serpentine shape as shown in Figure 11. The interface of the cooling garment and the heat exchanger was a sealed pass-through at the garment wall thereby insuring that the water in the cooling system was always protected from the contaminated environment. Both water and ice would be placed in the outside pouch to act as a heat sink for the recirculating cooling system water. This external pouch containing the heat exchanger could be refilled as required throughout the mission. The pouch was constructed of the same material as the rest of the garment and was lined with a polyurethane bag having a two track closure at the top and a drain valve at the bottom. A similar smaller polyurethane bag without a drain was used as a sump on the interior of the suit from which water was pulled by the pump to feed the cooling garment. The entire assembly had a weight of approximately 3 pounds.

Other cooling components. The pump used for the cooling system was a Tuthill 12 Volt DC Ryton pump (Part number 9058) having a throughput of 0.5 gallons per minute. Originally the pump was to be incorporated into the Environmental Control Unit. But because the use of the ECU in the HCPE was abandoned, the pump and two gel cell batteries (12 V) were housed in a plastic case having the approximate dimensions of 8" x 8" x 2" (approx. 5 lbs.). This case could either be worn attached to the user's hip or taped somewhere to the breathing apparatus. An adjustable internal suit harness was provide to support the weight of the cooling system. Quick disconnects were used to connect the TYGON tubing between cooling system components. A separate cooling sleeve was fabricated by ILC Dover for use with the Draeger BH174 rebreather. This sleeve was approximately 12 inches long and fit over the majority of the inhalation hose to the breathing mask. It was constructed of polyurethane coated nylon and had fittings on either end to allow the inflow and outflow of cooling water. The recommended configuration had the cooling sleeve after the cooling garment in the cooling system sequence (see Figure 9).

Communications System

The communications system for the HCPE was provided by the Coast Guard. A Remic model 7800 HL Portable transmitter/transceiver (49.86 MHz) and accessory throat microphone were planned for use with the ensemble. Considerations for the design of the outergarment included the head space requirements of this and other similar commercial communications systems. The Coast Guard felt that like the breathing apparatus, the outergarment should accomodate a large variety of communications systems to allow greater flexibility in use.



COOLING POUCH AND HEAT EXCHANGER DESIGN

Figure 11

CHAPTER 4

OVERALL ENSEMBLE TESTING

ILC Dover fabricated two prototype outergarments out of each material for testing the overall Hazardous Chemical Protective Ensemble. Of the two chlorinated polyethylene garments, one was constructed of 20 mil unsupported CPE, the other from 30 mil nylon supported CPE. These two different prototypes were constructed to demonstrate the relative wear performance of the supported versus unsupported materials. The six prototype garments were evaluated together with other ensemble components including the ILC Dover cooling system, Remic Corp. communications system and two different breathing systems (Draeger BG174 Rebreather and the Survivair 60 minute open-circuit SCBA). The principal purpose of the overall ensemble testing was determine the extent to which the outergarment and cooling system met Coast Guard requirements and the compatibility of the outergarment with supporting equipment within the ensemble. The evaluation consisted of two parts: protection factor measurements and manned stress testing.

Protection Factor Testing

The "protection factor" is a quantitative measure of the effectiveness of the ensemble in protecting the user from a hazardous chemical environment. It is an established means for measuring the integrity of encapsulating garments or equipment (particularly breathing system masks). Protection factors are determined by measuring the concentration of a "challenge" chemical agent both inside and outside the suit or other protective equipment; the ratio of external (ambient) to internal concentration measurements is the protection factor:

$$PF = \frac{\text{Ambient Concentration of Contaminant}}{\text{Concentration of Contaminant inside Suit}}$$

Challenge Agent (Contaminant). To date, most suit protection factor tests have been conducted using aerosols of chemical agents such as dioctyl phthalate (DOP) and dioctyl sebacate (DOS). ILC Dover originally proposed to use dichlorodifluoromethane (Freon 12) as a non-toxic, gaseous contaminate. However, their detection equipment did not have the capability to quantify Freon 12 over a sufficient concentration range. A large concentration range is necessary to measure large protections factors since the measurements are ratios; generally, protection factors are measured up to 10,000 or 100,000. ILC Dover then decided to use a the conventional DOS aerosol consisting of liquid droplets averaging 10 microns.

Testing Apparatus. Testing was carried out using an aluminum-lined 8' x 8' x 10' air-tight chamber at ILC Dover's plant in Frederica, Delaware. The chamber was equipped with air circulation fans to produce and maintain uniform challenge chemical concentrations throughout the chamber over the testing period. In the study, both the chamber and the ensemble were instrumented for gas monitoring. Aerosol concentrations were measured using an Air

Techniques Model TDA-50 Aerosol Tester which uses a detection technology based on light scattering (photometry). Equipment parameters used during the tests included:

Sample line intack - 2.5 liters per minute
Diluent air flow pressure - 4 inches water guage
Generator pressure - 6 psi
Equilibration time - 1.5 hours

One of the problems with this detection technique is its inability to distinguish types of aerosol; any aerosol (e.g. perspiration) or dust particles will deflect light resulting in an instrument reading. Instrument connections to the ensemble were via vinyl tubing through a pass-through bulkhead connector on the suit wall of the outergarment. Aerosol sampling was conducted at three locations within the garment--hood area, middle torso, and lower leg. This sampling scheme was used to determine the approximate locations of any leaks in the outergarment. Furthermore, aerosol droplets tend to fall to the ground with time.

Test Procedure. Two phases of protection factor testing were performed: mannequin testing to establish baseline performance characteristics, and manned testing to allow an analysis of the influence of body movements on the protection factor. Mannequin testing involved sampling of the test chamber and the three ensemble ports in a squential fashion every fifteen minutes over a two hour period. The manned testing introduced a suit subject into the ensemble who performed a series of exercises including arm movements, toe touches, and deep knee bends. The test chamber and three ensemble ports were sampled after each exercise. After the each complete test, the ensemble was visually examined for any wear and an inflation test was performed to assess the static integrity of the overgarment. The inflation test involved outergarment pressurization to 5 inches of water guage pressure, observing the pressure drop over time for several hours (if any), and soaping the suit exterior to determine leaks if a significant pressure drop was noted. Both a mannequin and manned protection factor test were conducted for each suit type (based on suit material) with the exception that no manned test was performed on the supported CPE suit prototype. Draeger BG174 Rebreathers were exclusively used for manned protection factor testing since this presented the worst case for chemical agent penetration (less suit exhaust air). The test protocol and the detailed procedures are given in Appendix C.

Testing Results. Tables of the raw measurements are provided in Appendix D. Test portection factors were calculated using the following formula:

$$PF = \frac{\dfrac{\text{Chamber conc. before exercise + Chamber conc. after exercise}}{2}}{\dfrac{\text{(Head + Torso + Foot Ensemble conc. measurements)}}{3}}$$

Table 22 gives the protection factor measurements for each of the outergarment types (by material) for both mannequin and manned tests. These protection factors have been rounded to two significant figures due to the imprecision in the averaging measurements. A number of the calculated protection factors were beyond the normal operating range of ILC Dover's equipment, i.e., the

TABLE 22

SUMMARY OF PROTECTION FACTOR TESTING

Test No.	Outer Garment	Type Test	Protection Factor
P-1-01	30 mil CPE (unsup.)	Mannequin	100,000*
P-1-02	20 mil CPE (sup.)	Mannequin	55,000
P-2-01	30 mil CPE (unsup.)	Manned	27,000
P-1-03	VITON/chlorobutyl	Mannequin	100,000*
P-2-03	VIOTN/chlorobutyl	Manned	64,000
P-2-04	Butyl rubber	Mannequin	100,000*
P-2-02	Butyl rubber	Manned	100,000*

* Protection factors exceeded limits of detectors

lower concentrations measured were below the sensitivity of the detection device. This reiterates the problem of achieving a large concentration range for measuring protection factors. The ILC Dover Penetrometer had a sensitivity of 0.1 ppm for the ensemble measurements and 100 ppm for chamber measurements (different scales were used) and could accurately measure protection factors up to 100,000. Some of the protection factors appeared to exceed this level.

Analysis of Protection Factor Measurements. No standard exists for assessing the integrity of a garment or equipment item based on protection factor measurements. Protection factors are most commonly measured for breathing apparatus face masks for determining how well they seal against the face of the user. Generally, protection factors on the order of 10,000 are considered 'good'. Several investigators have also reported that protection factors measured under ideal lab conditions are much higher than those measured during a work routine or during field use of the equipment. This observation is analogous to data in this study where manned protection factor tests had lower protection factors than their mannequin counterpart tests. Yet even manned protection factor tests yielded relative high measurements (greater than 10,000). Based on the reported protection factors, it appears that each of the suit types demonstrated a high level of integrity. It is impossible to determine if the lower protection factors for manned tests were the result of aerosol penetration into the suit or aerosol generated inside the outergarment by the suit subject via internal dust or perspiration. This phenomena could have been verified by running a blank protection factor test (with no aerosol generation)

Relative Comparison of Protection Factors. If the relative magnitude of the measured protection factors are any indication of suit integrity, then certain observations can be made. The butyl overgarment outperformed each of the other garments with protection factors for both mannequin and manned tests exceeding 100,000. The largest penetrations were noted for the supported 20 mil CPE overgarment. All other mannequin tests demonstrated protection factors over 100,000. Inspection of the 20 mil CPE outergarment following testing revealed a greater level of wear for suit particularly at critical seam areas (such as the crotch and armpits areas). This suit also failed the inflation test following the inspection and needed repair of some seams.

Manned Stress Testing

Manned stress testing was performed to assess the performance of the Hazardous Chemical Protective Ensemble during simulated work cycles. This testing involving evaluating the work stress of ensemble users by measuring their physiological responses during simulated work exercises. Test participants also subjectively evaluated the design and comfort of the ensemble. Test subjects included representatives from the National Strike Force (with at least one member from each Strike Team) and an ILC Dover suit subject. The manned stress testing was divided into two identical phases. A two month interval between phases allowed minor modifications to the suit prototypes, and redesign of the test protocol.

Testing Approach and Equipment. Each test subject was required to perform a series of two hour work cycles consisting of exercises and simulated work tasks. The subjects heart rate and core temperature were constantly monitored. In addition, the following parameters were measured:

ambient temperature
ambient humidity
inhalation temperature (inhalation hose)
exhalation temperature (exhalation hose)
cooling system inlet water temperature
cooling system outlet water temperature
ensemble (outergarment) internal temperature
ensemble (outergarment) internal pressure

Temperature measurements were made using thermocouples attached to cables going through a pass-through in the suit; suit pressure was measured using a pressure guage attached to a length of vinyl tubing passing through the suit wall. Each test subject performed one two hour cycle per test day. Testing was terminated at the completion of the two hour work cycle, when any of the physiological parameters exceeded the maximum limits (heart rate 180 bpm, core temperature 39°C), or at the request of the test subject. Prior to the manned stress testing of HCPE, each test subject performed two work cycles in 'work' clothes to establish baseline physiological parameters. After each test, the used overgarment was then inspected visually and by an inflation test.

Work Cycle Exercises and Simulated Tasks. The first phase of manned stress test were two hours in length and consisted of a 1/2 hour exercise period, a 1/2 hour treadmill test, and a one hour work period. The excerixe period entailed the following exercises:

1) Kneeling on each knee and both knees (repeated three times)

2) Duck squats with pivoting (repeated three times)

3) Body bends (repeated three times)

4) Arm extensions (repeated three times)

5) Body twists with subject's arms out (repeated three times)

6) Cross-body reaches (repeated three times)

7) Crawling on hand and knees for a distance of 20 feet

The suit subject rested for five minutes following the exercise routine and then repeated the entire exercise sequence once more. The treadmill test was conducted at 5 degrees of incline and a speed of 3 miles per hour. The suit subjects walked for one minute at those conditions and rested two minutes, repeating the process a total of ten times. The work period consisted of six tasks:

1) Lifting four boxes from the floor and placing them on a table

2) Placing a 55 gallon drum on handtruck and moving it 25 feet, removing the drum from the handtruck, putting back on the handtruck, and returning it to the original position

3) Uncoiling and coiling a 10 foot section of one inch diameter hose

4) Opening and closing an overhead valve

5) Removing and installing a bolt with a wrench

6) Removing and installing a screw with a screwdriver

These work tasks were repeated followed by a five minute rest period and the entire sequence repeated two additional times. The Draeger rebreather was able to provide sufficient breathing air during the entire work cycle. The Survivair SCBA needed replenishment of its air bottle midway through the tests. Appendix C provides a detailed procedure for the manned stress tests.

Test Conditions. All tests were conducted at the ILC Dover Plant in Frederica, Delaware indoors or inside a temperature and humidity controlled chamber. A number of environmental conditions were used during the performance of the manned stress tests. These included:

Ambient (temperature 23 - 26°C, relative humidity 45 - 55%)
High temperature (110°F), low relative humidity (10%)
High temperature (95°F), high relative humidity (85%)
Moderate temperature (30°F) with RH near saturation
Low temperature (0°F) with RH near saturation

Baseline tests (without wearing the ensemble) were conducted on each test subject at ambient and high temperature/low humidity conditions only. One test with each type of suit (by material) at each condition was performed. The work task portion of the work cycle was deleted for all tests conducted in the environmental chamber due to limited space (this reduced the test length to one hour). Tables 23 and 24 give lists of the test conditions, respective outergarments, and test subjects for each of the manned stress testing phases.

General Results for Phases I and II. A number of test failures were observed during phase I. These included both breakdowns of ensemble equipment (suit and cooling system leaks) and test instrumentation (environmental chamber, thermocouples, core temperature probe). As a result, the procedure and equipment status was reviewed between the two manned stress testing phases. Some outergarment prototypes were modified or repaired, a better passthrough in the outergarment was constructed, and new test instrumentation was obtained. One major change in the test plan was to reduce the number of test subjects from four to three thus providing more time for testing. Phase II generally went much more smoothly with only one test being aborted due to equipment problems. For this reason, the majority of test analysis was conducted using the results of Phase II. The basic test conditions and physiological results for each phase are presented in Tables 25 and 26. Ensemble equipment measurements are provided in Table 27.

General Observations. Due to the limitations in time and resources, it

TABLE 23

PHASE I - MANNED STRESS TESTING SCHEDULE

CONDITION	SUBJECT	OVERGARMENT
Ambient	ILC-1	Work Clothes
Ambient	USCG-1	Work Clothes
Ambient	USCG-2	Work Clothes
Ambient	USCG-3	Work Clothes
110°F, 10%RH	ILC-1	Work Clothes
110°F, 10%RH	USCG-1	Work Clothes
110°F, 10%RH	USCG-2	Work Clothes
110°F, 10%RH	USCG-3	Work Clothes
Ambient	ILC-1	Butyl #1
Ambient	USCG-1	CPE-20 Mil
Ambient	USCG-2	Viton #1
Ambient	USCG-3	CPE-30 Mil
Ambient	ILC-1	CPE-20 Mil
Ambient	USCG-1	Butyl #2
Ambient	USCG-2	CPE-30 Mil
Ambient	USCG-3	Viton #2
110°F, 10%RH	ILC-1	Viton #1
110°F, 10%RH	USCG-1	CPE-30 Mil
110°F, 10%RH	USCG-2	Butyl #1
110°F, 10%RH	USCG-3	CPE-20 Mil
90°F, 85% RH	ILC-1	CPE-30 Mil
90°F, 85% RH	USCG-1	Viton #2
90°F, 85% RH	USCG-2	CPE-20 Mil
90°F, 85% RH	USCG-3	Butyl #2
30°F	ILC-1	Butyl #1
RH Approaching	USCG-1	CPE-20 Mil
Saturation	USCG-2	Viton #1
	USCG-3	CPE-30 Mil
0°F	ILC-1	CPE-20 Mil
RH Approaching	USCG-1	Butyl #2
Saturation	USCG-2	CPE-30 Mil
	USCG-3	Viton #2

TABLE 24

PHASE II - MANNED STRESS TESTING SCHEDULE

CONDITION	SUBJECT	OVERGARMENT
Ambient	USCG-4	Work Clothes
Ambient	USCG-5	Work Clothes
Ambient	USCG-6	Work Clothes
110°F, 10%RH	USCG-4	Work Clothes
110°F, 10%RH	USCG-5	Work Clothes
110°F, 10%RH	USCG-6	Work Clothes
Rm Ambient	USCG-4	Butyl #1
Rm Ambient	USCG-5	Viton #1
Rm Ambient	USCG-6	CPE-30 Mil
110°F, 10%RH	USCG-4	CPE-30 Mil
110°F, 10%RH	USCG-5	Butyl #1
110°F, 10%RH	USCG-6	Viton #1
90°F, 85% RH	USCG-4	Viton #2
90°F, 85% RH	USCG-5	CPE-30 Mil
90°F, 85% RH	USCG-6	Butyl #2
30°F, RH Approaching Saturation	USCG-4	Butyl #1
	USCG-5	Viton #1
	USCG-6	CPE-30 Mil
0°F, RH Approaching Saturation	USCG-4	Butyl #2
	USCG-5	CPE-30 Mil
	USCG-6	Viton #2

TABLE 25

PHASE I MANNED STRESS TESTING GENERAL RESULTS

Test Number	Date	Test Subject	Test Conditions	Overgarment Type	Breathing Apparatus	Cooling System	Core Temp. Rise (°C)	Comments
S-1-01	11/1/83	MK3 Wyatt	Ambient	None	None	None	0.27	Completed
S-1-02	11/1/83	MSTCS Anthony	Ambient	None	None	None	0.69	Completed
S-1-03	11/1/83	DC3 Perkins	Ambient	None	None	None	0.57	Completed
S-1-04	11/2/83	A. Leslie	Ambient	None	None	None	0.69	Completed
S-2-01	11/3/83	DC3 Perkins	Ambient	30 mil CPE	Draeger	Yes	1.65	Completed
S-2-02	11/3/83	A. Leslie	Ambient	20 mil CPE	Draeger	Yes	—	Subject hyperventilated
S-2-03	11/4/83	MK3 Wyatt	Ambient	VITON/CB	Draeger	Yes	—	Cooling system leak
S-2-04	11/5/83	A. Leslie	Low Temp	VITON/CB	Draeger	Yes	0.30	Completed
S-2-05	11/5/83	MSTCS Anthony	Low Temp	20 mil CPE	Draeger	Yes	—	Overgarment leak
S-2-06	11/5/83	MK3 Wyatt	Low Temp	30 mil CPE	Draeger	Yes	0.60	Completed
S-2-07	11/7/83	A. Leslie	Low Temp	VITON/CB	Draeger	None	0.25	Completed
S-2-08	11/7/83	DC3 Perkins	Mod. Temp	20 mil CPE	Draeger	None	0.60	Completed
S-2-09	11/7/83	MK3 Wyatt	Mod. Temp	30 mil CPE	Draeger	None	—	No data taken
S-2-10	11/7/83	MSTCS Anthony	Mod. Temp	Butyl	Draeger	None	—	Suit failure
S-2-11	11/8/83	MSTCS Anthony	Mod. Temp	VITON/CB	Draeger	None	—	Aborted by Test Subject
S-2-12	11/8/83	MK3 Wyatt	HT, LH	None	None	None	0.15	Completed
S-2-13	11/8/83	A. Leslie	HT, LH	None	None	None	0.30	Completed
S-2-14	11/9/83	DC3 Perkins	HT, LH	None	None	None	0.45	Completed
S-2-15	11/9/83	MSTCS Anthony	HT, LH	None	None	None	0.50	Completed
S-2-16	11/9/86	MK3 Wyatt	HT, LH	30 mil CPE	Survivair	Yes	0.50	Completed
S-2-17	11/10/83	MSTCS Anthony	HT, LH	20 mil CPE	Survivair	Yes	—	Cooling system leak
S-2-18	11/10/83	DC3 Perkins	HT, LH	VITON/CB	Survivair	Yes	—	No data taken
S-2-19	11/11/83	A. Leslie	HT, HH	30 mil CPE	Draeger	Yes	—	Aborted by Test Subject
S-2-20	11/11/83	MK3 Wyatt	HT, HH	VITON/CB	Survivair	Yes	—	No data taken
S-2-21	11/11/83	DC3 Perkins	HT, HH	20 mil CPE	Survivair	Yes	—	No data taken
S-2-22	11/18/83	A. Leslie	Ambient	20 mil CPE	Draeger	Yes	2.50	Completed
S-2-23	12/1/83	A. Leslie	Ambient	VITON/CB	Draeger	Yes	—	No data taken

HT - High Temperature; LH - Low Humidity; HH - High Humidity

TABLE 26

PHASE II MANNED STRESS TESTING GENERAL RESULTS

Test Number	Date	Test Subject	Test Conditions	Overgarment Type	Breathing Apparatus	Cooling System	Core Temp. Rise (°C)	Comments
S-1-05	1/9/84	DC3 Perkins	Ambient	None	None	None	0.40	Completed
S-1-06	1/9/84	MK3 Wyatt	Ambient	None	None	None	0.25	Completed
S-1-07	1/9/84	DC2 Daharsh	Ambient	None	None	None	0.35	Completed
S-1-08	1/12/84	DC3 Perkins	HT, LH	None	None	None	0.70	Completed
S-1-09	1/12/84	MK3 Wyatt	HT, LH	None	None	None	0.55	Completed
S-1-10	1/12/84	DC2 Daharsh	HT, LH	None	None	None	0.55	Completed
S-2-24	1/10/84	MK3 Wyatt	Ambient	Butyl	Draeger	Yes	0.25	Completed
S-2-25	1/11/84	DC3 Perkins	Ambient	VITON/CB	Draeger	Yes	0.40	Completed
S-2-26	1/11/84	DC2 Daharsh	Ambient	30 mil CPE	Draeger	Yes	—	Core temp probe broken
S-2-27	1/12/84	DC3 Perkins	HT, LH	Butyl	Survivair	Yes	1.00	Completed
S-2-28	1/13/84	DC2 Daharsh	HT, LH	VITON/CB	Survivair	Yes	0.80	Completed
S-2-29	1/13/84	MK3 Wyatt	HT, LH	30 mil CPE	Survivair	Yes	0.62	Completed
S-2-30	1/16/84	DC2 Daharsh	HT, HH	Butyl	Survivair	Yes	0.70	Completed
S-2-31	1/16/84	MK3 Wyatt	HT, HH	VITON/CB	Survivair	Yes	0.37	Completed
S-2-32	1/17/84	DC3 Perkins	HT, HH	30 mil CPE	Survivair	Yes	0.50	Completed
S-2-33	1/17/84	DC2 Daharsh	Mod. Temp	Butyl	Survivair	No	0.30	Completed
S-2-34	1/18/84	MK3 Wyatt	Low Temp	VITON/CB	Draeger	Yes	0.54	Completed
S-2-35	1/18/84	DC2 Daharsh	Low Temp	30 mil CPE	Draeger	Yes	1.20	Completed
S-2-36	1/18/84	DC3 Perkins	Low Temp	Butyl	Draeger	Yes	0.26	Completed
S-2-37	1/19/84	MK3 Wyatt	Mod. Temp	30 mil CPE	Draeger	Yes	0.25	Completed
S-2-38	1/19/84	DC2 Daharsh	Mod. Temp	VITON/CB	Draeger	Yes	0.90	Completed

HT - High Temperature; LH - Low Humidity; HH - High Humidity

TABLE 27

PHASES I AND II MANNED STRESS TESTING EQUIPMENT RESULTS

Test Number	Overgarment Type	Inlet Air Temp. Range	Outlet Air Temp. Range	Inlet Water Temp. Range	Outlet Water Temp. Range	Ensemble Pres. Range (in. Water)	Ensemble Temp. Range
S-2-01	30 mil CPE	28.5 - 38.5	33.2 - 40.0	22.0 - 19.0	25.0 - 34.0	0 - 2.0*	29.5 - 38.0
S-2-04	VITON/CB	21.0 - 24.0	25.0 - 28.0	20.0 - 24.0	22.0 - 25.0	0 - 2.0*	20.0 - 24.0
S-2-06	30 mil CPE	18.0 - 21.0	24.0 - 27.0	15.0 - 27.0	18.0 - 21.0	0 - 2.0*	18.0 - 21.0
S-2-07	VITON/CB	17.0 - 23.0	23.0 - 24.0	No cooling	No cooling	0 - 2.0*	17.0 - 20.0
S-2-08	20 mil CPE	24.0 - 37.0	27.0 - 33.0	No cooling	No cooling	0 - 2.0*	27.0 - 35.0
S-2-16	30 mil CPE	26.0 - 29.0	29.0 - 34.0	15.0 - 19.0	17.0 - 21.0	2.0 - 3.5	25.0 - 31.0
S-2-22	20 mil CPE	25.0 - 39.0	29.0 - 37.0	21.0 - 28.0	21.0 - 29.0	0 - 2.0*	26.0 - 30.0
S-2-24	Butyl	17.0 - 25.0	27.5 - 29.5	15.0 - 20.5	22.0 - 24.0	0 - 2.0*	19.0 - 25.0
S-2-25	VITON/CB	21.0 - 23.5	26.0 - 32.0	16.0 - 20.0	21.5 - 28.0	0 - 2.0*	23.5 - 30.5
S-2-27	Butyl	30.0 - 32.0	29.0 - 33.0	16.0 - 25.0	27.5 - 28.5	1.5 - 3.5	26.5 - 32.0
S-2-28	VITON/CB	28.0 - 33.0	28.5 - 33.5	20.0 - 27.0	26.5 - 28.0	1.5 - 3.5	26.5 - 32.0
S-2-29	30 mil CPE	28.0 - 33.0	30.5 - 33.5	No data	25.0 - 29.0	1.0 - 3.0	24.5 - 29.5
S-2-30	Butyl	28.5 - 31.5	24.0 - 30.0	25.0 - 31.0	19.0 - 25.0	1.5 - 3.0	23.0 - 26.5
S-2-31	VITON/CB	29.0 - 30.5	26.5 - 30.5	17.0 - 22.0	19.0 - 24.0	1.0 - 3.5	24.0 - 29.0
S-2-32	30 mil CPE	30.0 - 33.0	26.0 - 33.0	No data	24.5 - 29.0	1.0 - 3.5	26.0 - 29.0
S-2-33	Butyl	19.5 - 29.5	23.5 - 31.0	No cooling	No cooling	1.5 - 3.5	10.0 - 27.0
S-2-34	VITON/CB	8.5 - 16.5	22.5 - 26.5	No data	0.5 - 19.5	No data	-2.0 - 21.5
S-2-35	30 mil CPE	17.5 - 20.5	25.5 - 27.0	No data	1.0 - 22.5	No data	-2.0 - 24.5
S-2-36	Butyl	20.0 - 27.0	28.5 - 29.5	0.0 - 15.0	9.0 - 26.0	0 - 2.0*	9.0 - 31.0
S-2-37	30 mil CPE	14.5 - 22.5	25.5 - 28.0	No data	20.0 - 26.0	0 - 2.0*	12.0 - 26.5
S-2-38	VITON/CB	18.0 - 22.0	21.5 - 29.0	14.0 - 23.0	22.0 - 23.5	0 - 2.0*	13.5 - 23.5

All temperature ranges in °C; * - overgarment required repressurization when used with rebreather.

was impossible to test each subject at each condition in each ensemble configuration (outergarment/breathing apparatus combination). Such a test plan would have required 108 tests for three suit subjects. Rather it was the intent of the test plan to gain general assessments on how well the HCPE performed in terms of function, fit, and comfort. Therefore, it is impossible to make specific conclusions on the results between different test conditions or ensemble configurations. General observations that can be made with respect to the data include:

1) **Effect of Ensemble Outergarment** - Core temperatures were higher for test subjects wearing the overgarments compared to baseline tests. There was no way to distinguish heat effects between each outergarment type. The high temperature conditions (both low and high humidity) causes the greatest rises in core temperature. However, low temperature conditions also significantly affected the test subject core temperature in some cases. Future tests must isolate the various conditions and ensemble configurations by subject to determine their respective effects on the subject's physiology.

2) **Effect of Ensemble Cooling System** - The cooling effect provided by the ensemble cooling system is uncertain. In some tests, particularly those at ambient or moderate temperature conditions, the cooling system appeared to prevent a large core temperature rise. However, under high heat conditions, the ability of the cooling system to stabilize core temperature is questionable. Further work is necessary to determine the differences in subject physiological response with and without the cooling system.

3) **Effect of Ensemble Breathing System** - Mixed results were found with the use of the two types of breathing systems. In many cases, especially high heat conditions, the rebreather caused high temperatures in the ensemble. Part of the heat buildup may be due to partial ineffectiveness of the cooling sleeve on the rebreather inhalation hose. Breathing air from the open-circuit system was not cooled and generally reflected the conditions of the test.

Subjective Comments (based on test subject critique responses).

1) Overgarment. The general design of the outergarment was found to be functional and allow a wide degree of fit for the test subjects in this study. Test subjects rated the butyl suit as most comfortable, then VITON/chlorobutyl, and the CPE suit as least comfortable. The CPE suit became very stiff at the lower temperatures. The two track closures were difficult to operate in cold conditions. The length of the closure was found to be too short for easy donning and doffing. The outergarment visor tended to fog over at low temperature and high humidity conditions.

2) Ensemble Cooling System. The ensemble cooling system was well-liked by all test particpants. It gave an apparent 'cool' feeling under all conditions for which it was operated. The major disadvantage of the cooling system was the bulkiness of the pump unit and the occasional disconnection or crimping of cooling tubes within the

ensemble. The cooling sleeve for the rebreather seemed effective however it made the breathing hose too stiff which in turn restricted movement.

3) Ensemble Breathing Systems. The high heat release of the Draeger BG174 rebreather was found a disadvantage since the heat was not only transmitted to the breathing air but also to the wearer's back (due to poor insulation of the system). This made its use uncomfortable in the hot conditions. The rebreather was also heavier and more difficult to use compared with the Survivair open-circuit SCBA. The outergarment accomodated both types of breathing systems, however, the top of the SCBA air bottle did tend to rub against the back of the outergarment in the vicinity of the closure. The rebreather could not maintain a positive pressure inside the outergarment. Several times during the test, the outergarment needed inflation to lift the suit off the subject's shoulders. On the other hand, the SCBA kept the suit over-inflated and required the user to occasionally force the air out of the suit. The test subjects recommended that appropriate sized outergarment exhaust valves be used to relieve this problem.

4) Communications System. The REMIC system was found to operate well as part of the HCPE. However, the attenna protruding from the headset affected head movement inside the outergarment. No attempt was made to evaluate the radio's operational capabilities.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study has successfully identified chemical protective materials and integrated these materials into the design of a outergarment for the Coast Guard Hazardous Chemical Protective Ensemble. The focus of this work was to find materials which could supplement butyl rubber for protection against as many CHRIS chemicals as possible. Material selection criteria were based on chemical resistance, physical properties (for indicating strength and durability), and the material's capability for forming high integrity seams. A uniform outergarment design was then developed which could incorporate each of the materials and accomodate other ensemble components such as the breathing, cooling, and communications systems.

Under the current technology, protection against the majority of CHRIS chemicals can only be achieved with a multimaterial suit system. In this investigation, the outergarment materials--butyl rubber, chlorinated polyethylene, and VITON/chlorobutyl laminate each using a FEP/Surlyn laminate visor--are collectively compatible with 74% of the chemicals commonly spilled (for which test data exist). When the number of spills are considered using past frequencies, spill compatability is 92% for the selected materials (for which test data exist). Material - chemical compatability is relative to the pass/fail conditions chosen. For this study, materials were judged incompatible when they exhibited moderate to severe degradation effects (visual, weight change, elongation change) following one-sided immersion or a permeation breakthrough of less than one hour to the with a particular chemical.

The Hazardous Chemical Protective Ensemble was developed as a complete personnel protection package incorporating the outergarment together with full body cooling system, a breathing system, and a communications systems. ILC Dover designed the outergarment for flexibility to fit different sizes of users and their protective equipment. It was also developed with features to provide the highest level of protection to chemical vapors and splashes consistent with the U. S. Environmental Protection Agency's definition of Level A protection. These features include a pressure sealing zipper located on the back of the garment with a splash cover, integral gloves and sock-like booties, and a outergarment pressurization system. The cooling system also designed by ILC Dover was directly interfaced to the outergarment with a full body cooling garment, pump, and field-reserviceable ice pouch/heat exchanger. Government provided breathing and communications systems easily fit inside the garment and completed the ensemble package.

Of the two types of ensemble laboratory testing performed, the protection factor testing was conclusive in demonstrating that the ensemble provided a high level of integrity against external chemical (aerosol) challenges. The results obtained from the manned stress testing were not easily compared due to the large number of variables associated with each test. The design of the these experiments allowed only qualitative assessments about the performance of the ensemble under different environmental conditions. In cases where sufficient basis existed to make a comparison, the results varied and few generalizations could be made. The most valuable feedback from this testing were thc subjective comments of the test subjects.

While this development has proposed both materials and a design for the Hazardous Chemical Protective Ensemble, further testing and documentation are required to determine the capabilities and limitations of this ensemble. Among these are:

1) Further chemical resistance testing of the outergarment and visor materials to additional chemicals; Following the protocol of this study, both immersion and permeation testing should be performed for other CHRIS chemicals to determine suit compatibility recommendations using the modified criteria developed in this study.

2) Determining a strategy for handling 'unknown' chemicals, chemical mixtures, or chemicals for which no material compatibility data is available; Suit selection problems will arise when each of these situations are present. A means must be established to determine the appropriate type outergarment to wear for personal protection.

3) More extensive chemical resistance testing of other outergarment components which may be contacted by chemicals; Such components as the suit closure, exhaust valves, and seams should all be tested against representative chemicals to determine if their chemical resistance is the same as that provided by the outergarment and visor materials. If not, components fabricated from other materials should be selected which provide equivalent protection. The outergarment is only as good as the weakest material in its construction.

4) The decontamination potential of these materials should be more extensively investigated. Tests in this study for the decontamination of the selected protective clothing materials were hampered by the lack of a quantitative methods to determine the level of contamination before and after the simple decontamination method. Such methods are needed to allow consideration for reusing outergarments which have been exposed to chemicals in the field. Otherwise, any significant chemical exposure to a suit should warrant its disposal.

5) Tests should be conducted to measure the positive pressure in the suit during simulated work exercises. These tests should examine the range of pressure fluctuation inside the outergarment and determine if negative pressure situations occur which will allow external chemical vapors to penetrate the suit. These test should determine the appropriate parameters (cracking pressure and maximum flow rate) for sizing the outergarment exhaust valves.

6) Protection factor testing should involve chemical challenge agents more representative of chemicals that are encountered in the field. Conventional aerosols consist of liquid droplets much larger than small chemical solvent molecules which are more likely to penetrate suit seams and closures.

7) The effect of the cooling system should be quantitatively defined. Experiments should be run to determine how much cooling is provided by the in-suit cooling system versus wearing no cooling suit under different environmental conditions. The physiological response of test subjects should be monitored by measuring heart rate, core temperature, internal ensemble temperature, and inlet/outlet cooling water temperatures. The amount of cooling effect provided by the system should be weighed against the additional burden (weight and mobility) placed on the user. This data should also be used to establish heat stress considerations for using the ensemble.

REFERENCES

1. "Chemical Hazards Response Information System (CHRIS)", U. S. Coast Guard Commandant Instruction M16465.12. Stock No. 050-012-00215-1 (Obtainable from Superintendent of Documents, Government Printing Office, Washington, D. C. 20402).

2. J. V. Friel, M. J. McGoff, and S. J. Rodgers. "Material Development Study for a Hazardous Chemical Protective Clothing Outfit," Coast Guard Report No. CG-D-58-80. MSA Research Corporation, Evans City, Pennsylvannia. August 1980. (NTIS Accession No. AD-A-095993).

3. R. Algera. "Development of a Hazardous Chemical Protective Ensemble," Phase I Interim Report for Coast Guard Contract DTCG23-81-C-20003. ILC Dover, Inc., Frederica, Delaware. November 1982.

4. "Standard Operating Safety Guidelines." U. S. Environmental Protection Agency, Office of Emergency and Remedial Response, Hazardous Response Support Division, Environmental Response Branch, Edison, New Jersey. November 1984.

5. M. J. McGoff and J. W. Maustellar. "Feasibility Study of a Self-Contained Environmental Control Unit," Coast Guard Report No. CG-D-04-79. MSA Research Corporation, Evans City, Pennsylvannia. November 1978. (NTIS Accession No. AD-A-071154).

APPENDIX A

CHRIS CODES AND CHEMICAL NAMES FOR COMPOUNDS CONSIDERED IN THIS STUDY

APPENDIX A

CHRIS CODES AND CHEMICAL NAMES FOR COMPOUNDS CONSIDERED IN THIS STUDY

CHRIS CODE	CHEMICAL COMPOUND	TESTING CONDUCTED
AAD	ACETALDEHYDE	Immersion only
ABM	ACETYL BROMIDE	Immersion only
ACC	ACETYL CHLORIDE	Immersion only
ACF	ALLYL CHLOROFORMATE	Immersion only
ACL	ALUMINUM CHLORIDE	Immersion only
ACN	ACRYLONITRILE	Immer./Permeation
ADN	ADIPONITRILE	Immersion only
ALA	ALLYL ALCOHOL	Immer./Permeation
ALC	ALLYL CHLORIDE	Immer./Permeation
APC	ANTIMONY PENTACHLORIDE	Immersion only
APF	ANTIMONY PENTAFLUORIDE	Not tested
ARL	ACROLEIN	Immersion only
ASC	ANISOYL CHLORIDE	Immersion only
ASU	AMMONIUM BISULFATE	Immersion only
ATC	ALLYL TRICHLOROSILANE	Immersion only
ATM	ANTIMONY TRICHLORIDE	Immersion only
ATS	n-AMYLTRICHLOROSILANE	Not tested
BAD	ISO-BUTYRALDEHYDE	Not tested
BAM	n-BUTYL AMINE	Immer./Permeation
BBR	BENZYL BROMIDE	Immersion only
BCL	BENZYL CHLORIDE	Immer./Permeation
BCY	BARIUM CYANIDE	Immer./Permeation
BCS	BUTYLTRICHLOROSILANE	Not tested
BDE	BISPHENOL A DIGLYCIDYL ETHER	Immersion only
BEC	BERYLLIUM CHLORIDE	Not tested
BEN	BERYLLIUM NITRATE	Immersion only
BNZ	BENZENE	Immer./Permeation
BPF	BROMINE PENTAFLUORIDE	Not tested
BPT	BENZENE PHOSPHORUS THIODICHLORIDE	Immer./Permeation
BRM	BROMINE	Immersion only
BRT	BORON TRICHLORIDE	Immersion only
BTB	BORON TRIBROMIDE	Immersion only
BTF	BROMINE TRIFLUORIDE	Not tested
BTO	1,2-BUTYLENE OXIDE	Immer./Permeation
BTR	n-BUTYRALDEHYDE	Not tested
CAC	CHLOROACETYL CHLORIDE	Immersion only
CBB	CARBON DISULFIDE	Immer./Permeation
CBO	CARBOLIC OIL	Immer./Permeation
CBR	CYANOGEN BROMIDE	Immersion only
CBS	COBALT SULFATE	Not tested
CCL	CYANOGEN CHLORIDE	Immersion only
CDN	CHLORDANE	Immersion only
CES	CUPRIETHYLENEDIAMINE SOLUTION	Immersion only

APPENDIX A (continued)

CHRIS CODES AND CHEMICAL NAMES FOR
COMPOUNDS CONSIDERED IN THIS STUDY

CHRIS CODE	CHEMICAL COMPOUND	TESTING CONDUCTED
CHA	CYCLOHEXYL AMINE	Immer./Permeation
CHT	CYCLOHEXENYLTROCHLOROSILANE	Not tested
CLX	CHLORINE	Immersion only
CMA	CHROMIC ANHYDRIDE	Immersion only
CME	CHLOROMETHYL METHYL ETHER	Immersion only
CMH	CUMENE HYDROPEROXIDE	Immersion only
CMS	CADMIUM SULFATE	Not tested
CON	COBALT NITRATE	Not tested
COU	COUMAPHOS	Immersion only
CPL	CHLOROPICRIN, LIQUID	Immersion only
CRF	CHLOROFORM	Immer./Permeation
CRP	CHLOROPRENE	Immersion only
CSA	CHLOROSULFONIC ACID	Immersion only
CTA	CROTONALDEHYDE	Immer./Permeation
CTD	4-CHLORO-o-TOLUIDINE	Immer./Permeation
CTF	CHLORINE TRIFLUORIDE	Not tested
CUM	CUMENE	Immer./Permeation
DAC	DIMETHYLACETAMIDE	Immer./Permeation
DAL	DECALDEHYDE	Not tested
DBA	DI-n-BUTYL AMINE	Immer./Permeation
DBO	o-DICHLOROBENZENE	Immer./Permeation
DCB	DICHLOROBUTENE	Immer./Permeation
DCP	2,4-DICHLOROPHENOL	Not tested
DCV	DICHLOROVON	Immersion only
DDB	DODECYLBENZENE	Immer./Permeation
DEE	DICHLOROETHYL ETHER	Immer./Permeation
DFA	DIFLUOROPHOSPHORIC ACID, ANHYDROUS	Immersion only
DIH	DIISOPROPYLBENZENE HYDROPEROXIDE	Immersion only
DIS	DISULFTON	Immersion only
DIU	DIURON	Immersion only
DMD	DIMETHYLDICHLOROSILANE	Immer./Permeation
DNA	DI-n-PROPYLAMINE	Immersion only
DNB	m-DINITROBENZENE	Not tested
DPD	DIPHENYLDICHLOROSILANE	Immersion only
DPP	DICHLOROPROPANE	Immer./Permeation
DSL	DIMETHYL SULFIDE	Immersion only
DTC	DODECYLTRICHLOROSILANE	Not tested
DTN	DEMETON	Immersion only
DUR	DURSBAN	Immersion only
DZN	DIAZINON	Not tested
DZP	DI-p-CHLOROBENZOYL PEROXIDE	Not tested
EAC	ETHYL ACRYLATE	Immer./Permeation
EAI	2-ETHYLHEXYL ACRYLATE, INHIBITED	Immer./Permeation

APPENDIX A (continued)

CHRIS CODES AND CHEMICAL NAMES FOR
COMPOUNDS CONSIDERED IN THIS STUDY

CHRIS CODE	CHEMICAL COMPOUND	TESTING CONDUCTED
EAM	ETHYLAMINE	Immersion only
ECF	ETHYL CHLOROFORMATE	Immersion only
ECS	ETHYLDICHLOROSILANE	Not tested
EDB	ETHYLENE DIBROMIDE	Immer./Permeation
EDC	ETHYLENE DICHLORIDE	Immer./Permeation
EDR	ENDRIN	Immersion only
EHA	ETHYLHEXALDEHYDE	Not tested
ENB	ETHYLIDENENORBORNENE	Immersion only
EOX	ETHYLENE OXIDE	Immersion only
EPD	ETHYL PHOSPHOROTHIOIC DICHLORIDE	Immersion only
EPP	ETHYL PHOSPHORODICHLORIDATE	Immersion only
EPS	ETHYLPHENYLDICHLOROSILANE	Not tested
ESF	ENDOSULFANE	Immersion only
ETC	ETHYLENE CYANOHYDRIN	Immer./Permeation
ETM	ETHYL METHACRYLATE	Immer./Permeation
ETO	ETHION	Immersion only
ETS	ETHYLTRICHLOROSILANE	Immersion only
FCL	FERRIC CHLORIDE	Immersion only
FFB	FERROUS FLUOROBORATE	Immersion only
FMS	FORMALDEHYDE SOLUTION	Immer./Permeation
FSA	FUOROSULFONIC ACID	Immersion only
FSL	FLUOSILICIC ACID	Immersion only
FXX	FLUORINE	Not tested
GTA	GLUTERALDEHYDE	Immersion only
HAL	n-HEXALDEHYDE	Not tested
HBR	HYDROGEN BROMIDE	Immersion only
HCL	HYDROCHLORIC ACID	Immer./Permeation
HCN	HYDROGEN CYANIDE	Immersion only
HDC	HYDROGEN CHLORIDE	Immer./Permeation
HFA	HYDROFLUORIC ACID	Immersion only
HFX	HYDROGEN FLUORIDE	Immersion only
HMI	HEXAMETHYLENEIMINE	Immer./Permeation
HMT	HEXAMETHYLENETETRAMINE	Immersion only
IAI	ISODECYL ACRYLATE	Immersion only
IAM	ISOBUTYLAMINE	Immersion only
IBN	ISOBUTYRONITRILE	Immer./Permeation
IDA	ISODECALDEHYDE	Not tested
IOC	ISOOCTALDEHYDE	Immer./Permeation
IPE	ISOPROPYL ETHER	Immer./Permeation
IPM	ISOPROPYL MERCAPTAN	Immersion only
IVA	ISOVALERALDEHYDE	Immer./Permeation
LPM	LAURYL MERCAPTAN	Immersion only
MAM	METHYL ACRYLATE	Immersion only

APPENDIX A (continued)

CHRIS CODES AND CHEMICAL NAMES FOR COMPOUNDS CONSIDERED IN THIS STUDY

CHRIS CODE	CHEMICAL COMPOUND	TESTING CONDUCTED
MCH	METHYL CHLOROFORMATE	Immersion only
MCS	METHYLDICHLOROSILANE	Immersion only
MFA	MOTOR FUEL, ANTIKNOCK COMPOUNDS CONTAINING LEAD ALKYLS	Not tested
MPD	METHYL PHOSPHONOTHOIC DICHLORIDE	Not tested
MPY	1-METHYL PYROLIDONE	Immersion only
MSO	MESITYL OXIDE	Immer./Permeation
MTB	METHYL BROMIDE	Immersion only
MTS	METHYLTRICHLOROSILANE	Immersion only
MVK	METHYL VINYL KETONE	Immersion only
NAA	NITRILOTRIACETIC ACID AND SALTS	Immersion only
NAC	NITRIC ACID	Immer./Permeation
NCT	NAPHTHA: COAL TAR	Immersion only
NIC	NICOTINE	Immer./Permeation
NIE	o-NITROTOLUENE	Immersion only
NOX	NITROGEN TETROXIDE	Immersion only
NSV	NAPHTHA: SOLVENT	Immer./Permeation
NTA	2-NITROANILINE	Not tested
NTB	NITROBENZENE	Immer./Permeation
NTC	NITROSYL CHLORIDE	Not tested
NTX	NITRIC OXIDE	Immersion only
OLM	OLEUM	Not tested
OXA	OXALIC ACID	Immersion only
PAA	PERACETIC ACID	Immersion only
PBR	PHOSPHOROUS TRIBROMIDE	Immersion only
PCB	POLYCHLORINATED BIPHENYL	Immer./Permeation
PCM	PERCHLOROMETHYL MERCAPTAN	Immersion only
PCP	PENTACHLOROPHENOL	Not tested
PDL	PHENYLDICHLOROARSINE (LIQUID)	Not tested
PHG	PHOSGENE	Immersion only
PHN	PHENOL	Immersion only
PMN	n-PROPYL MERCAPTAN	Immersion only
PPO	PHOSPHOROUS OXYCHLORIDE	Immersion only
PPT	PHOSPHOROUS TRICHLORIDE	Immersion only
PRA	n-PROPYLAMINE	Immer./Permeation
PTL	PETROLATUM	Immersion only
SAC	SULFURIC ACID, SPENT (50%)	Immer./Permeation
SCL	SULFURYL CHLORIDE	Immersion only
SDS	SODIUM SULFIDE	Immersion only
SFA	SULFURIC ACID	Immer./Permeation
SFD	SULFUR DIOXIDE	Immersion only
SFM	SULFUR MONOCHLORIDE	Immersion only
STC	SILICON TETRACHLORIDE	Immersion only

APPENDIX A (continued)

CHRIS CODES AND CHEMICAL NAMES FOR
COMPOUNDS CONSIDERED IN THIS STUDY

CHRIS CODE	CHEMICAL COMPOUND	TESTING CONDUCTED
STR	STRYCHNINE	Immersion only
SXX	SULFUR (LIQUID)	Not tested
TAP	p-TOLUENE SULFONIC ACID	Immer./Permeation
TCL	TRICHLOROETHYLENE	Immersion only
TDI	TOLUENE-2,4-DIISOCYANATE	Immer./Permeation
TEB	TRIETHYLBENZENE	Not tested
TEC	TETRACHLOROETHANE	Immer./Permeation
TED	TETRAETHYL DITHIOPYROPHOSPHATE	Not tested
TEL	TETRAETHYL LEAD	Not tested
TEN	TRIETHYLAMINE	Immer./Permeation
TES	2,4,5-T (ESTERS) BUTYL 2,4,5-TRICHLOROPHENOXYACETATE	Immersion only
THF	TETRAHYDROFURAN	Immer./Permeation
TMA	TRIMETHYLAMINE	Immersion only
TMC	TRIMETHYLCHLOROSIALNE	Immer./Permeation
TML	TETRAMETHYL LEAD	Not tested
TPG	THIOPHOSGENE	Immersion only
TPH	TRICHLOROPHENOL	Not tested
TTT	TITANIUM TETRACHLORIDE	Immersion only
TXP	TOXAPHENE	Immersion only
VCI	VINYLIDENECHLORIDE, INHIBITED	Immersion only
VCM	VINYL CHLORIDE	Immer./Permeation
VFI	VINYL FLUORIDE, INHIBITED	Immersion only
VIS	VINYLTRICHLOROSILANE	Immersion only
ZCL	ZINC CHLORIDE	Immersion only
ZCT	ZIRCONIUM TETRACHLORIDE	Immersion only
ZFB	ZINC FLUOROBORATE	Immersion only
ZPF	ZINC POTASSIUM FLUORIDE	Immersion only

APPENDIX B

SURVEY OF SPILLED SUBSTANCES FROM NATIONAL RESPONSE CENTER FOR 1981-1982

APPENDIX B

TABLE B-1 RANKED LIST OF SPILLED SUBSTANCES

Compound	Annual Number of Spills	Significance Code of Worst Spill	Toxicity Class TLV	Toxicity Class IDLH	Toxicity Class STEL	Carcinogenicity Class	Chemical Class
Sulfuric Acid	426	Q	2	2	-	0	23
Hydrochloric Acid, Hydrogen Chloride	305	Q	1	2	-	0	23
Sodium Hydroxide (Sol'n or dry)	193	Q	1	1	-	0	23
Nitric Acid	101	T	1	2	2	0	23
Methyl Alcohol	96	R	0	0	0	0	1,4
Ammonia	94	G	0	1	1	1	23
Acetic Acid	90	A	1	1	1	0	1,7
Xylenes	61	A	0	0	0	1	14
Potassium Hydroxide (Sol'n or dry)	56	R	2	2	-	0	23
Toluene	50	T	0	0	0	1	14
Styrene	46	K	0	0	1	2	2,14
Ethyl Acrylate	38	A	1	0	1	2	2,8
Phenol	38	A	1	2	2	1	17
Acetone	37	A	0	0	0	0	1,6
Toluene Diisocyanate	37	A	3	3	3	0	9,14
Acetaldehyde	35	A	0	0	0	1	14
Hydrofluoric Acid, Hydrogen Fluoride	35	Q	1	2	-	0	23
Hydrogen Peroxide	35	R	2	2	2	0	23,25
Methyl Ethyl Ketone	26	A	0	0	0	0	1,6
Naptha, Coal Tar	22	J	0	0	-	0	22
Chlorine	20	Q	2	2	2	0	23
Formaldehyde	18	Q	1	2	-	2	1,6
Hydrogen Sulfide	18	A	1	1	1	0	23
Vinyl Acetate	15	K	1	-	1	3	2,8
Oleum	13	S	2	2	-	0	23
Pyridine	13	A	1	-	2	1	21
Tetrahydrofuran	13	K	0	0	0	0	27,32
Thionyl Chloride	13	A	-	-	-	0	23
Acrylonitrile	12	A	1	3	-	3	2,9
Formic Acid	11	A	1	2	-	0	1,7
Acetic Anhydride	10	C	1	1	-	0	1,7
Parathion	10	Q	1	2	2	0	26
Acrylic Acid	9	A	1	-	-	0	2,7
Benzene	9	≤P	1	0	1	3	14
Hydrofluosilicic Acid*	9	A	-	-	-	0	23
Nitromethane	9	A	0	1	0	0	1,19
Phosphorous Oxychloride	9	A	3	-	3	0	23

APPENDIX B (continued)

TABLE B-1 RANKED LIST OF SPILLED SUBSTANCES

Compound	Annual Number of Spills	Significance Code of Worst Spill	Toxicity Class TLV	Toxicity Class IDLH	Toxicity Class STEL	Carcinogenicity Class	Chemical Class
Hexane	8	V	0	0	0	0	1
Nitrobenzene	8	≤P	2	1	2	0	14,19
Phosphorous (White)	8	Y	3	-	-	0	23
Chloropicrin	7	S	3	3	3	2	3,19
Creosote	7	K	1	1	-	1	17
Hydrazine	7	≤P	3	2	-	3	11
Propionic Acid	7	A	1	0	1	0	1,7
Aniline	6	A	1	2	2	0	10,14
Carbon Disulfide	6	B	0	1	-	0	12
Chlorosulfonic Acid	6	A	1	-	-	0	3,13
Cyclohexane	6	A	0	0	0	0	1,32
Thioglycolic Acid	6	A	2	-	-	0	7,12
Trichloroethylene	6	≤P	0	1	0	3	1,3
Cyanides (Sodium, Potassium Sol'n)	5	R	1	2	-	0	23
Mercury	5	J	3	3	-	1	23
Methylene Chloride	5	A	0	0	0	1	1,3
Petroleum Ether	5	B	-	-	-	0	24
Sulfur Dioxide	5	A	1	2	2	0	23
Acetonitrile	4	A	0	0	1	0	1,9
Chloroform	4	≤P	1	1	1	3	1,3
Cumene Hydroperoxide* **	4	≤P	-	-	-	2	14,25
Dimethyl Sulfate	4	A	3	-	-	3	15
Ethyl Silicate	4	Q	1	1	1	0	1,31
Phosphorous Pentasulfide	4	R	1	2	-	0	23
Sulfur Chloride	4	A	2	2	2	0	23
Titanium Tetrachloride**	4	Q	1	-	-	0	23
Allyl Chloride	3	A	2	2	2	2	2,3
Bromine	3	A	3	3	3	0	23
Dioxane	3	≤P	0	2	-	3	27,32
Ethyl Mercaptan	3	B	2	0	2	0	1,12
Methyl Chloride	3	A	0	0	1	2	1,3
Trichloroacetic Acid	3	A	2	-	-	0	3,7
Trichloro-s-triazine**	3	A	-	-	-	1	3,21
Valeric Acid*	3	Q	-	-	-	0	1,7
Vinyl Chloride	3	≤P	1	-	-	3	2,3
Benzoyl Chloride	2	Q	-	3	-	0	14,30
Benzyl Chloride	2	A	2	3	-	3	3,14
Butyl Amine	2	A	1	0	-	0	1,10
Carbon Tetrachloride	2	A	1	1	1	3	1,3
Chlordane	2	≤P	3	2	-	3	2,3,33

APPENDIX B (continued)

TABLE B-1 RANKED LIST OF SPILLED SUBSTANCES

Compound	Annual Number of Spills	Significance Code of Worst Spill	Toxicity Class TLV	Toxicity Class IDLH	Toxicity Class STEL	Carcino-genicity Class	Chemical Class
Cyanogen Bromide	2	≤P	2	-	-	0	3,9
Ethylene Dichloride	2	-	1	1	1	3	1,3
Hydrocyanic Acid	2	≤P	1	2	-	0	23
Methyl Bromide	2	≤P	1	0	1	0	1,3
Silicon Tetrachloride	2	S	-	-	-	0	23
Cyanogen	1	≤P	2	-	-	0	9
Dichlorobenzene	1	≤P	0	0	-	0	3,14
Ethylene Oxide	1	K	1	2	-	2	1,5,32
Furfural	1	A	1	1	2	1	2,6,27,33
Hydrogen Cyanide	1	≤P	1	2	-	0	23
Malathion	1	≤P	2	1	-	0	26
Phosphorous Tribromide*	1	A	-	-	-	0	23
Propylene Oxide	1	≤P	0	0	-	2	1,5,32
Tetrachloroethylene	1	J	0	1	0	3	2,3
Tetraethyl lead	1	≤P	3	3	-	2	16
Allyl Alcohol	NR	-	1	2	1	0	2,4
Cyanogen Chloride	NR	-	2	-	-	0	3,9
1,2-Dichloropropane	NR	-	1	-	0	1	1,3
Dichlorvos	NR	-	3	-	3	2	26
Epichlorohydrin	NR	-	1	2	2	3	1,3,5,32
Fluorine	NR	-	2	2	2	0	23
Methyl Hydrazine	NR	-	2	-	-	2	11
Nitrogen Tetroxide	NR	-	1	2	1	0	23
o-Nitrotoluene	NR	-	1	1	1	0	14,19
Phosgene	NR	-	3	3	-	1	30
Sulfur	NR	-	1	-	1	0	23
Tetramethyl lead	NR	-	3	3	-	2	16

*IDLH class numbers determined by assuming that the IDLH class number of a chemically similar compound is the same.

**IDLH class numbers taken to be the same as those for compounds with similar toxicity data.

Tables B-2, B-3, and B-4 provide supplementary information for spill codes and chemical classes (toxicity, carcinogen, functional group)

APPENDIX B (continued)

TABLE B-2 WORST SPILL SIGNIFICANCE CODES

Significance Code	Property Damage $1,000-$10,000	$10,000	Injuries 1-10	10	Deaths 1-10	10	Rank
Y[a]		X		X		X	1
X		X		X		X	2
W	X			X		X	3
H				X		X	4
F			X			X	5
D						X	6
G				X	X		7
E			X		X		8
V		X			X		9
U	X				X		10
C					X		11
T		X		X			12
S	X			X			13
B				X			14
R		X	X				15
Q	X		X				16
A			X				17
Z		people evacuated					18
K		X					19
J	X						20
<P[b]	1 or more containers broken						21

[a]Y differs from X in that it includes a high percentage of containers failed.
[b]<P = codes P,L,M,N,I, all of which refer to different percentages of containers failed.

APPENDIX B (continued)

TABLE B-3 TOXICITY AND CARCINOGEN CLASSES

Toxicity Classes

Class	TLV	IDLH	STEL
3	0.1ppm	10ppm	1ppm
2	0.1ppm ≤ TLV ≤ 1ppm	10ppm ≤ IDLH ≤ 100ppm	1ppm ≤ STEL ≤ 10ppm
1	1ppm ≤ TLV ≤ 10ppm	100ppm ≤ IDLH ≤ 1000ppm	10ppm ≤ STEL ≤ 100ppm
0	10ppm	1000ppm	100ppm

Carcinogen Classes

Class	Description
3	Compound is a probable carcinogen.
2	Compound is a possible carcinogen.
1	Compound is a questionable carcinogen.
0	Compound is not a carcinogen or no data is available.

APPENDIX B (continued)

TABLE B-4 - CHEMICAL GROUPS

Group Number	Chemical Classification
1	Compounds all of whose Carbon-Carbon Bonds are Saturated
2	Compounds which contain one or more Unsaturated Carbon-Carbon Bonds and are Not Aromatics.
3	Halogen Compounds
4	Alcohols
5	Glycols and Epoxides
6	Aldehydes and Ketones
7	Carboxylic Acids and Anhydrides
8	Esters and Amides
9	Nitriles and Isocyanates
10	Amines and Imines
11	Hydrazines
12	Organic Sulfur Compounds
13	Sulfonic Acids, Sulfoxides
14	Aromatic Compounds
15	Organic Sulfates
16	Organometallics
17	Phenols
18	Halogenated Phenols
19	Nitro Compounds
20	Fused-ring Aromatic Hydrocarbons
21	Heterocyclic Nitrogen Compounds
22	Mixed Hydrocarbons and Oils
23	Inorganics
24	Ethers and Halogenated Ethers
25	Peroxides
26	Organophosphorus Compounds
27	Heterocyclic Oxygen Compounds
28	Heterocyclic Sulfur Compounds
29	Organoarsenic Compounds
30	Carbonyl Halides
31	Organosilicon Compounds
32	Saturated Cyclic Compounds
33	Unsaturated Non-aromatic Cyclic Compounds

APPENDIX C

DETAILED TEST PLAN AND PROCEDURES
FOR EVALUATING THE
HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

LIST OF CONTENTS

1.0 INTRODUCTION

This document sets forth the test plan and detailed test procedures by which prototype units of the Hazardous Chemical Protective Ensemble (HCPE) design are to be subjected to Laboratory Ensemble Testing. Successful completion of the Laboratory Ensemble Test Program will establish a quantitative measure of the effectiveness of the HCPE garment in protecting the user in a hazardous environment, and provide a measure of the effectiveness of the ensemble in terms of work performance, work stress, comfort, and other physiological factors.

1.1 SCOPE

The scope of the testing described herein is limited to ensemble testing of the HCPE required to verify the operational characteristics of the HCPE design that cannot be verified by other means (material sample testing, vendor certification, acceptance testing, etc.)

1.2 OBJECTIVE

The objective of this document is to provide a test program integrated to develop the test results and data required to verify the operational characteristics of the HCPE design.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this test plan to the extent specified herein:

ILC DOCUMENT NO. 0000-73070

Standard Operating Procedure for Stress Testing Procedure (SOP 1005).

3.0 TEST PROGRAM

The laboratory testing of the HCPE consists of two phases: protection factor testing, and manned stress testing.

3.1 PROTECTION FACTOR TESTING

Protection factor testing will provide a quantitative measure of the effectiveness of the HCPE in protecting the user from a hazardous environment. Protection factor testing will consist of two parts: mannequin testing to establish baseline performance characteristics, and manned testing to establish the influence of body motions on the protection factor. Protection factor testing will occur at the test facilities of ILC Dover.

3.2 MANNED STRESS TESTING

Manned stress testing will be performed to assess the performance of the HCPE during work cycles. The testing will provide a quantitative evaluation of the work stress by measurements of physiological factors throughout the work cycle as well as subjective evaluations by the test subjects regarding ensemble comfort. Manned stress testing will be performed at the test facilities of ILC Dover.

3.3 TEST SCHEDULE

Laboratory Ensemble Testing of the HCPE shall be performed in accordance with the schedule shown in Figure 1.

3.4 GENERAL REQUIREMENTS

3.4.1 Test Identification

Each test performed as part of the Laboratory Ensemble Testing shall be singularly identified as shown below:

```
X-X-XX
| |  └─Test Number
| └─Test Condition
|     1-Mannequin or Control
|     2-Manned Test
└─Test Phase
   P-Protection Factor
   S-Manned Stress
```

3.4.2 Test Procedures

Properly approved test procedures shall be available for each test activity. The procedures shall contain detailed instructions to the level necessary to conduct the test in an adequate manner. In the event that the instructions are found to be inadequate, all activity shall be terminated immediately and resumed only when appropriate and approved changes have been effected.

3.4.3 Notification of Test

ILC shall provide the USCG Technical Monitor with 15 days prior notice of each phase of the Laboratory Ensemble Testing.

3.4.4 Test Area Conditions

Ambient conditions for conducting the Laboratory Ensemble Testing shall be specified in the applicable detailed test procedures. The test area shall be maintained at a level of cleanliness comparable to that of offices and laboratories in which good housekeeping is practiced. Smoking and consumption of beverages or food shall not be permitted.

3.4.5 Test Article Handling and Storage

Throughout the performance of the Laboratory Ensemble Testing, extreme care shall be exercised in the handling of test articles to preclude damage. Special care shall be taken during transportation and folding, and during engagement and disengagement of components, plugs, fixtures, umbilicals, etc. Where applicable, protective covers shall be in place at all times except during test, inspections, cleaning, or repair. After each test segment, the test garment shall be sanitized and stored in an appropriate location.

3.4.6 Test Responsibilities and Accountability

3.4.6.1 Test Engineer

The test engineer shall be fully responsible for the technical direction and timely progress of testing and related activities. The test engineer will be responsible for initiating all testing in the form of Test Preparation Sheets, and advise all cognizant personnel, with ample advance notice, of test commencement.

The test engineer shall be accountable to the Program Manager and shall advise the Program Manager of any delay which, in his opinion, would significantly affect the normal progress and schedule of the test program.

3.4.6.2 Test Conductor

The test conductor shall be responsible for carrying out all tests in accordance with detailed test procedures, and recording all data in the manner required by the test procedure. The test conductor shall be accountable to the Manager, Test Lab, and shall be responsible for ensuring that all Test Lab equipment and instrumentation is calibrated and in proper working order prior to the beginning of each test sequence.

3.4.6.3 Test Subjects

Test subjects for the manned test portions of the test program shall be USCG Strike Team members. ILC suit subjects shall be available to participate in the manned testing should manpower contraints limit the number of Strike Team members present for manned testing.

3.5 DOCUMENTATION

Documentation of all test activity shall be in accordance with applicable ILC documents. Copies of all data generated during and pertinent to this test program shall be submitted to the Test Engineer immediately upon availability.

3.5.1 Test Preparation Sheet (TPS)

The TPS (See Figure 2) provides the authority for

a) Performance of a test activity

b) Any change to this test plan

c) Implementation of any activity affecting test articles used in the performance of this test program when not authorized by any other appropriate document.

Each TPS shall be approved by the Program Manager, Quality Engineer, and Manufacturing Engineer prior to initiation of testing. No other concurrance or approval is required for the performance of this test program.

The number of the TPS system shall be unique to this program

807-X-X-XX-XX

TPS Number

Test Number

A TPS log (See Figure 3) shall be included as a part of the detailed test procedure peculiar to each test and shall be maintained by the test conductor.

3.5.2 Data Sheet Forms

Appropriate data sheet forms shall be included as a part of the detailed test procedure peculiar to each test. The test conductor shall enter all test data required by the test procedure as well as any other pertinent information such as test subject comments on comfort and mobility, etc.

A | CONFIGURATION CHANGE

B | MAINTENANCE OR TEST

ILC INDUSTRIES INC.

TEST PREPARATION SHEET

STEP NO	WORK DESCRIPTION (PRINT OR TYPE)	CCA	ECO AND OR DR	WRF	INSPECTION STAMP GFE			OTHER REFERENCE NO (CHANGE NO)
					GFE STORES	ILC	DCASR	

DATE

DATE

DATE

DATE

REMOVED ITEMS LISTED IN STEPS ________ TO BE RETURNED TO GOVERNMENT STORES TAGGED AND LABELED "WITHHOLD". TAG TO SHOW TPS AND DR NOS OR OTHERS AS REQUIRED

HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

LABORATORY TEST PROGRAM

TPS LOG

TPS NUMBER	DATE	TITLE

3.5.3 Discrepancy Report

A discrepancy report will be written to document each discrepancy or problem with the HCPE that occurs during the course of the test program. Each report shall contain a description of the discrepancy with photographs where applicable, an analysis of the cause of the discrepancy, and corrective action to be taken to prevent the discrepancy from recurring during testing or in future units. Each discrepancy report shall be prepared by the test engineer and approved by the Quality Assurance Engineer and the Program Manager.

A discrepancy log shall be included as a part of the detailed test procedure peculiar to each test and shall be maintained by the Test Conductor.

3.5.4 Test Report

At the conclusion of the Laboratory Ensemble Test Program, ILC shall prepare a test report to be included as a section of the program final report. The test report shall include a description of all testing, procedures, discrepancies and corrective action, and a summary with detailed test results. Included in the ILC test report will be a subjective report from USCG Strike Team members participating in the test program.

Significant test results or problems will be conveyed to the program Technical Monitor by telecon as they occur.

4.0 DETAILED TEST PROCEDURES

The Laboratory Ensemble Testing of the HCPE shall be conducted in accordance with the detailed test procedures attached.

TEST PROCEDURE

PROTECTION FACTOR TESTING

FOR

HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

1.0 SCOPE

1.1 OBJECTIVE

The objective of the Protection Factor testing of the HCPE is to quantitatively determine a protection factor for the HCPE for each type of material and construction.

1.2 METHOD OF APPROACH

The protection factor is defined by the following:

$$PF = \frac{\text{Ambient Concentration of Contaminant}}{\text{Concentration of Contaminant Inside Ensemble}}$$

To determine the PF, each ensemble will be instrumented to monitor the concentration of a challenge gas. The PF test will consist of two phases: mannequin testing to establish baseline performance characteristics, and manned testing to allow an analysis of the influence of body movements on the PF.

2.0 SUPPORT FACILITIES AND EQUIPMENT

ILC Protection Factor Test Chamber

Air Techniques Model TDA-50 Aerosol Tester

3.0 REQUIREMENTS

3.1 GENERAL REQUIREMENTS

This test shall be conducted with the general requirements of ILC Document 807-1 paragraph 3.4 and as detailed below.

3.1.1 Test Sequence

The sequence of operations detailed in section 4.0 of this procedure is mandatory except as noted. Rearrangement of the sequence shall be permitted only with the approval of the Test Engineer of the Program Manager.

3.1.2 Test Documentation

All testing performed shall be documented by the documentation forms detailed in section 5.0 of this procedure. Each individual test shall have a complete set of documentation forms completed by the test conductor.

3.1.3 Verification

The successful completion of each operation shall be indicated by the initials of the test conductor and verification by the test engineer in the columns provided for this purpose.

4.0 OPERATIONS

4.1 PRE-TEST PROCEDURE

A. Identify the test article.

1.	Outergarment	P/N
		S/N
2.	Cooling Garment	P/N
		S/N
3.	Breathing System	P/N
		S/N

B. Verify successful completion of outergarment and cooling garment acceptance tests. Attach Test Data Sheets as a part of this completed procedure.

4.2 TEST PROCEDURE

4.2.1 Mannequin Test

A. Begin aerosol generation, allow test chamber to equilibrate over next 1.5 hours.

B. Install ensemble on mannequin in area remote from test chamber.

C. Inflate outergarment to operating pressure.

D. Sample ensemble from each of three sampling ports to determine background levels of challenge agent.

E. Establish chamber concentration by sampling 3 times for 1 minute at 2 minute intervals.

F. Sampling of the suit will be accomplished via 1/4" polypropylene tubing attached to each of three sampling ports in the suit, one in the torso, one near the head/shoulder area, and one in the lower leg. Sampling duration will be 1 minute per port.

G. Repeat chamber and ensemble sampling every 15 minutes for two hours.

H. Exhaust the test chamber for 15 minutes to reduce aerosol concentration to a low level.

I. Remove mannequin and ensemble from the test chamber.

4.2.2 Manned Test

A. Begin aerosol generation, allow test chamber to equilibrate over next 1.5 hours.

B. Don ensemble in area remote from test chamber.

C. Inflate outergarment to operating pressure and fill cooling system.

D. Sample ensemble from each of three sampling ports to determine background levels of challenge agent.

E. Introduce suit subject into testing chamber.

F. Establish chamber concentration by sampling 3 times for 1 minute at 2 minute intervals.

G. Conduct first manned exercise, 3 minute exercise consisting of moving arms. Arms will be fully extended horizontally and moved simultaneously to the forward position and then returned to the horizontal extended position. There shall be approximately 30 repetitions of this movement each minute.

H. Sampling of the suit will be accomplished via 1/4" polypropylene tubing attached to each of three sampling ports in the suit, one in the torso, one in the head/shoulder area, and one in the lower leg. Sampling duration will be 1 minute per port.

I. At 15 minutes following the first test the second 3 minute test shall be performed consisting of bending at the waist and touching the toes (or as close as possible). There shall be approximately 10 repetitions of this exercise each minute of the test.

J. Sample room atmosphere as in Step F.

K. Sample ensemble as in Step H.

L. At 15 minutes after Step #9 the next 3 minute exercise shall be performed which consists of a deep knee bend and return to the upright position. There shall be approximately 10 repetitions of this exercise each minute of the test.

M. Sample room atmosphere as in Step F.

N. Sample ensemble as in Step H.

O. Repeat Steps F through N.

P. Exhaust the test chamber for 15 minutes to reduce aerosol concentration to a low level.

Q. Remove test subject from test chamber.

R. Doff garment.

4.3 POST-TEST PROCEDURE

A. Perform a visual examination of the test ensemble.

B. Perform an overpressure and pressure drop test on the test outergarment.

C. Attach test data sheets as a part of this completed procedure.

5.0 TEST DOCUMENTATION FORMS

Test information and data shall be recorded on the attached forms.

TEST DATA SHEET NO. 1

PROTECTION FACTOR TESTING

HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

Test Number:

Date:

Test Subject:

Pre-Test Procedure

Outergarment	P/N	
	S/N	
Cooling Garment	P/N	
	S/N	
Breathing System	P/N	
	S/N	

Test Procedure

Verify exercise scenario if applicable.

Record data on test data sheet No. 2.

TEST DATA SHEET NO. 2

Movement	Sensitivity of Measurement	Reading

Generator Pressure:
Diluent Air Flow:
Sampling Rate:

TEST PROCEDURE

MANNED STRESS TESTING

FOR

HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

1.0 SCOPE

1.1 OBJECTIVE

The objective of the Manned Stress testing of the HCPE is to assess the performance of the HCPE during work cycles by measuring physiological factors throughout the work cycle.

1.2 METHOD OF APPROACH

Each test subject will be required to perform a series of two hour work cycles consisting of exercises and simulated work tasks. Each garment will be replaced after each two hour scenario for inspection and sanitizing. Each test subject will perform one two hour work cycle per test day. Testing will be terminated on the request of the subject, when any physiological parameter reaches the maximum limit, or at completion of the two hour work cycle by one subject. Prior to manned stress testing of the HCPE, each test subject shall perform two work cycle scenarios in conventional work clothes for familiarization and to establish baseline physiological parameters.

2.0 SUPPORT FACILITIES AND EQUIPMENT

ILC Environmental Chamber

Fiberboard Box (Gross Wt, 20 lbs)

55 Gallon Drum

Handtruck

Handwheel Valve

Hose

Screwdriver

Wrench

Treadmill

3.0 REQUIREMENTS

3.1 GENERAL REQUIREMENTS

This test shall be conducted with the general requirements of ILC Document 807-1 paragraph 3.4 and as detailed below.

3.1.1 Test Sequence

The sequence of operations detailed in Section 4.0 of this procedure is mandatory except as noted. Rearrangement of the sequence shall be permitted only with the approval of the Test Engineer or the Program Manager.

3.1.2 Test Documentation

All testing performed shall be documented by the documentation forms detailed in Section 5.0 of this procedure. Each individual test shall have a complete set of documentation forms completed by the test conductor.

3.1.3 Verification

The successful completion of each operation shall be indicated by the initials of the test conductor and verification by the test engineer in the columns provided for this purpose.

4.0 OPERATIONS

4.1 PRE-TEST PROCEDURE

A. Identify the test article

1. Outer garment P/N

   S/N

2. Cooling Garment P/N

   S/N

3. Breathing System P/N

   S/N

B. Verify successful completion of outergarment and cooling garment acceptance test. Attach Test Data Sheets as part of this completed procedure.

4.2 TEST PROCEDURE

The manned stress tests are to be two hours in length consisting of a 1/2 hour exercise period, a 1/2 hour treadmill test, and a 1 hour work period.

A. Donn ensemble.

B. Inflate outergarment to operating pressure and fill cooling system.

C. Perform exercise scenario.

1. Kneel on left knee, kneel on both knees, kneel on right knee, stand. Repeat three times.

2. Duck squat, pivot right, pivot left, stand. Repeat three times.

3. Stand erect. Bend body to left and return, bend body forward and return, bend body to right and return. Repeat three times.

4. Stand erect. Extend arms overhead, then bend elbows. Repeat three times.

5. Stand erect. Extend arms perpendicular to the sides of torso. Twist torso left and return, twist torso right and return. Repeat three times.

6. Stand erect. Cross-body reach arms across chest. Repeat three times.

7. Crawl on hands and knees for a distance of 20 feet.

8. Repeat steps 1 through 7 for 10 minutes.

9. Rest for 5 minutes.

10. Repeat steps 1 through 9.

D. Perform treadmill test.

1. Set treadmill at 5° of incline and 3 mph speed.

2. Walk for 1 minute and rest for 2 minutes.

3. Repeat step 2, 10 times.

E. Perform work tasks at room temperature

1. Lift four boxes from the floor and place on a table. Return boxes to floor.

2. Place a 55 gallon drum on a handtruck and move 25 feet. Remove drum from handtruck. Replace drum on handtruck and move to original position.

3. Remove drum from handtruck.

4. Uncoil and coil hose.

5. Open overhead valve. Close overhead valve.

6. Remove and install bolt with wrench.

7. Remove and install screw with screwdriver.

8. Repeat steps 1 through 7 for 15 minutes.

9. Rest for 5 minutes.

10. Repeat steps 1 through 9 two additional times.

F. Doff ensemble.

4.3 POST-TEST PROCEDURE

A. Perform a visual examination of the test ensemble.

B. Perform an overpressure and pressure drop test on the test outergarment.

C. Attach test data sheets as a part of this completed procedure.

5.0 TEST DOCUMENTATION FORMS

Test information and data shall be recorded on the attached forms.

TEST DATA SHEET NO. 1

MANNED STRESS TESTING

HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

Test Number:

Date:

Test Subject:

Pre-Test Procedure

Outergarment	P/N	
	S/N	
Cooling Garment	P/N	
	S/N	
Breathing System	P/N	
	S/N	

Exercise Test

Verify performance of exercise scenario.

Record data on test data sheet No. 2.

Treadmill Test

Verify performance of treadmill scenario.

Record data on test data sheet No. 2.

Work Task Test

Verify performance of work task scenario.

Record data on test data sheet No. 2.

TEST DATA SHEET NO. 2

MANNED STRESS TESTING
HAZARDOUS CHEMICAL PROTECTIVE ENSEMBLE

TIME	AMBIENT TEMP	AMBIENT RH	CORE TEMP	INHALATION AIR TEMP	EXHALATION AIR TEMP	INLET WATER TEMP	OUTLET WATER TEMP	ENSEMBLE PRESSURE	ENSEMBLE TEMPERATURE

APPENDIX D

PROTECTION FACTOR TESTING RESULTS

PROTECTION FACTOR TEST DATA

Test Number: P-1-01 Outergarment: 30 mil CPE unsupported
Type Test: Mannequin Breathing Apparatus: not applicable

Time (min.)	Type/Location of Measurement	Detector Scale	Detector Reading	Protection Factor
00	Suit background	0.1	2.0	
	Chamber	100.0	88.0	
15	Head	0.1	1.0	
	Torso	0.1	1.0	76,500
	Foot	0.1	1.5	
	Chamber	100.0	91.5	
30	Head	0.1	1.0	
	Torso	0.1	1.0	93,750
	Foot	0.1	1.0	
	Chamber	100.0	96.0	
45	Head	0.1	1.0	
	Torso	0.1	1.0	92,550
	Foot	0.1	1.0	
	Chamber	100.0	89.0	
60	Head	0.1	0.5	
	Torso	0.1	0.5	137,000
	Foot	0.1	1.0	
	Chamber	100.0	92.0	
75	Head	0.1	0.5	
	Torso	0.1	0.5	187,000
	Foot	0.1	0.5	
	Chamber	100.0	95.0	
90*	Head	0.1	0.5	
	Torso	0.1	0.1	286,500
	Foot	0.1	0.5	
	Chamber	100.0	96.0	
105*	Head	0.1	0.5	
	Torso	0.1	0.1	180,000
	Foot	0.1	0.5	
	Chamber	100.0	84.0	
120	Head	0.1	0.1	
	Torso	0.1	0.1	455,000
	Foot	0.1	0.1	
	Chamber	100.0	67.0	
			AVERAGE	188,500

* Chamber evacuation fans accidently activated between 90 and 105 minutes

PROTECTION FACTOR TEST DATA

Test Number: P-1-03 Outergarment: VITON/chlorobutyl
Type Test: Mannequin Breathing Apparatus: not applicable

Time (min.)	Type/Location of Measurement	Detector Scale	Detector Reading	Protection Factor
00	Suit background	0.1	1.0	
	Chamber	100.0	73.5	
15	Head	0.1	0.5	
	Torso	0.1	1.0	68,500
	Foot	0.1	2.0	
	Chamber	100.0	85.0	
30	Head	0.1	1.0	
	Torso	0.1	0.5	101,500
	Foot	0.1	1.0	
	Chamber	100.0	84.0	
45	Head	0.1	1.0	
	Torso	0.1	0.5	125,750
	Foot	0.1	0.5	
	Chamber	100.0	82.0	
60	Head	0.1	0.5	
	Torso	0.1	0.1	75,000
	Foot	0.1	0.5	
	Chamber	100.0	83.0	
75	Head	0.1	0.5	
	Torso	0.1	0.5	167,000
	Foot	0.1	0.5	
	Chamber	100.0	84.0	
90	Head	0.1	0.1	
	Torso	0.1	0.1	850,500
	Foot	0.1	0.1	
	Chamber	100.0	86.0	
105	Head	0.1	0.1	
	Torso	0.1	0.1	865,000
	Foot	0.1	0.1	
	Chamber	100.0	87.0	
120	Head	0.1	0.1	
	Torso	0.1	0.1	885,000
	Foot	0.1	0.1	
	Chamber	100.0	90.0	
			AVERAGE	191,750

PROTECTION FACTOR TEST DATA

Test Number: P-1-03 Outergarment: Butyl rubber
Type Test: Mannequin Breathing Apparatus: not applicable

Time (min.)	Type/Location of Measurement	Detector Scale	Detector Reading	Protection Factor
00	Suit background	0.1	0.2	
	Chamber	100.0	79.0	
15	Head	0.1	0.1	
	Torso	0.1	0.1	780,000
	Foot	0.1	0.1	
	Chamber	100.0	77.0	
30	Head	0.1	0.1	
	Torso	0.1	0.1	775,000
	Foot	0.1	0.1	
	Chamber	100.0	78.0	
45	Head	0.1	0.1	
	Torso	0.1	0.1	790,000
	Foot	0.1	0.1	
	Chamber	100.0	80.0	
60	Head	0.1	0.1	
	Torso	0.1	0.1	785,000
	Foot	0.1	0.1	
	Chamber	100.0	77.0	
75	Head	0.1	0.1	
	Torso	0.1	0.1	760,000
	Foot	0.1	0.1	
	Chamber	100.0	75.0	
90	Head	0.1	0.1	
	Torso	0.1	0.1	790,000
	Foot	0.1	0.1	
	Chamber	100.0	83.0	
105	Head	0.1	0.1	
	Torso	0.1	0.1	825,000
	Foot	0.1	0.1	
	Chamber	100.0	82.0	
120	Head	0.1	0.1	
	Torso	0.1	0.1	815,000
	Foot	0.1	0.1	
	Chamber	100.0	81.0	
			AVERAGE	775,000

PROTECTION FACTOR TEST DATA

Test Number: P-1-02 Outergarment: 20 mil CPE (supported)
Type Test: Mannequin Breathing Apparatus: not applicable

Time (min.)	Type/Location of Measurement	Detector Scale	Detector Reading	Protection Factor
00	Suit background	0.1	1.0	
	Chamber	100.0	92.0	
15	Head	0.1	11.0	
	Torso	0.1	11.0	85,000
	Foot	0.1	11.0	
	Chamber	100.0	95.0	
30	Head	0.1	9.0	
	Torso	0.1	13.0	30,250
	Foot	0.1	9.0	
	Chamber	100.0	92.0	
45	Head	0.1	8.0	
	Torso	0.1	7.5	41,000
	Foot	0.1	7.0	
	Chamber	100.0	93.0	
60	Head	0.1	7.0	
	Torso	0.1	6.0	49,000
	Foot	0.1	6.0	
	Chamber	100.0	93.0	
75	Head	0.1	5.5	
	Torso	0.1	6.0	54,500
	Foot	0.1	5.5	
	Chamber	100.0	92.0	
90	Head	0.1	4.5	
	Torso	0.1	4.0	70,250
	Foot	0.1	5.0	
	Chamber	100.0	98.0	
105	Head	0.1	4.0	
	Torso	0.1	4.0	79,500
	Foot	0.1	4.0	
	Chamber	100.0	93.0	
120	Head	0.1	3.0	
	Torso	0.1	3.0	31,500
	Foot	0.1	3.0	
	Chamber	100.0	96.0	
			AVERAGE	55,135

PROTECTION FACTOR TEST DATA

Test Number:	P-2-01	Outergarment:	30 mil CPE (unsupported)
Type Test:	Manned	Breathing Apparatus:	Draeger BG174
		Test Subject:	DC2 C. WYATT

Movement (Time)	Type/Location of Measurement	Detector Scale	Detector Reading	Protection Factor
Initial	Head	0.1	10.0	
	Torso	0.1	10.0	8,900
	Foot	0.1	10.0	
	Chamber	100.0	89.0	
Arm Extensions	Head	0.1	3.0	
30/minute	Torso	0.1	3.5	86,500
3 minutes	Foot	0.1	4.0	
	Chamber	100.0	93.0	
Bend at Waist	Head	0.1	2.5	
10/minute	Torso	0.1	3.0	40,000
3 minutes	Foot	0.1	1.5	
	Chamber	100.0	94.0	
Deep Knee Bends	Head	0.1	8.0	
10/minute	Torso	0.1	10.0	10,500
3 minutes	Foot	0.1	8.5	
	Chamber	100.0	93.0	
Arm Extensions	Head	0.1	11.0	
30/minute	Torso	0.1	12.0	7,900
3 minutes	Foot	0.1	12.0	
	Chamber	100.0	92.0	
Bend at Waist	Head	0.1	13.0	
10/minute	Torso	0.1	15.0	7,200
3 minutes	Foot	0.1	10.0	
	Chamber	100.0	91.0	
Deep Knee Bends	Head	0.1	10.0	
10/minute	Torso	0.1	12.0	8,900
3 minutes	Foot	0.1	8.5	
	Chamber	100.0	---*	
			AVERAGE	26,900

* Test subject overheated and was removed from the test chamber; the cooling vest was not worn in the ensemble

PROTECTION FACTOR TEST DATA

Test Number: P-2-02
Type Test: Manned

Outergarment: Butyl rubber
Breathing Apparatus: Draeger BG174
Test Subject: Andy Leslie (ILC Dover)

Movement (Time)	Type/Location of Measurement	Detector Scale	Detector Reading	Protection Factor
Initial	Head	0.1	6.0	
	Torso	0.1	5.0	16,500
	Foot	0.1	5.0	
	Chamber	100.0	86.0	
Arm Extensions	Head	0.1	2.0	
30/minute	Torso	0.1	2.0	48,000
3 minutes	Foot	0.1	1.5	
	Chamber	100.0	90.0	
Bend at Waist	Head	0.1	1.0	
10/minute	Torso	0.1	1.0	108,500
3 minutes	Foot	0.1	0.5	
	Chamber	100.0	91.0	
Deep Knee Bends	Head	0.1	0.5	
10/minute	Torso	0.1	0.5	138,000
3 minutes	Foot	0.1	1.0	
	Chamber	100.0	93.0	
Arm Extensions	Head	0.1	0.5	
30/minute	Torso	0.1	0.5	138,500
3 minutes	Foot	0.1	1.0	
	Chamber	100.0	92.0	
Bend at Waist	Head	0.1	0.5	
10/minute	Torso	0.1	0.5	182,000
3 minutes	Foot	0.1	0.5	
	Chamber	100.0	90.0	
Deep Knee Bends	Head	0.1	0.5	
10/minute	Torso	0.1	0.5	182,000
3 minutes	Foot	0.1	0.5	
	Chamber	100.0	92.0	
			AVERAGE	133,000

PROTECTION FACTOR TEST DATA

Test Number:	P-2-03	Outergarment:	VITON/chlorobutyl
Type Test:	Manned	Breathing Apparatus:	Draeger BG174
		Test Subject:	Andy Leslie (ILC Dover)

Movement (Time)	Type/Location of Measurement	Detector Scale	Detector Reading	Protection Factor
Initial	Head	0.1	2.0	
	Torso	0.1	2.0	46,500
	Foot	0.1	1.5	
	Chamber	100.0	85.0	
Arm Extensions 30/minute 3 minutes	Head	0.1	0.5	
	Torso	0.1	1.0	104,000
	Foot	0.1	1.0	
	Chamber	100.0	89.5	
Bend at Waist 10/minute 3 minutes	Head	0.1	1.5	
	Torso	0.1	1.0	77,500
	Foot	0.1	1.0	
	Chamber	100.0	93.0	
Deep Knee Bends 10/minute 3 minutes	Head	0.1	1.5	
	Torso	0.1	1.0	69,900
	Foot	0.1	1.5	
	Chamber	100.0	93.0	
Arm Extensions 30/minute 3 minutes	Head	0.1	1.5	
	Torso	0.1	1.5	69,900
	Foot	0.1	1.0	
	Chamber	100.0	93.0	
Bend at Waist 10/minute 3 minutes	Head	0.1	1.5	
	Torso	0.1	1.5	62,500
	Foot	0.1	1.5	
	Chamber	100.0	95.0	
Deep Knee Bends 10/minute 3 minutes	Head	0.1	1.5	
	Torso	0.1	2.0	19,200
	Foot	0.1	1.5	
	Chamber	100.0	97.0	
			AVERAGE	64,300

END

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